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ABSTRACT

This document is designed to help senior high school students study remote sensing technology and techniques in relation to the environmental sciences. It discusses the acquisition, analysis, and use of ecological remote data. Material is divided into three sections and an appendix. Section One is an overview of the basics of remote sensing. Section Two contains selected readings which report formal research in agriculture, land use, geology, water resources, marine resources, and the environment. Section Three is composed of fundamental laboratory exercises which explore map reading and analysis, characteristics of the visible spectrum, and other relevant areas. The appendix contains supplemental references. Document includes numerous photographs and drawings, as well as study guides after each chapter. (MA)

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REMOTE SENSING AND THE EARTH

U.S. DEPARTMENT OF HEALTH,
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This document is available from the School Board of Brevard County, Instructional Services Division, Project Remote Sensing, 1274 South Florida Avenue, Rockledge, Florida 32955 at $9.74 per copy.

DEDICATION TO STUDENTS

"May this material assist you in your formal education and prepare you for your future experiences in life."

The School Board of Brevard County is extremely pleased to have been able to work with the National Aeronautics and Space Administration at John F. Kennedy Space Center in the development of this remote sensing document for students.

This document will bring present day technological processes into the classroom so that students may be involved in reviewing the various applications of science to today's ecological problems.

The document stresses the essentials of the electromagnetic spectrum; the applications of science to agriculture, geology, hydrology, marine resources, land use planning, and the environment; as well as a student laboratory activity section.

The School Board of Brevard County would especially like to commend Mr. Raymond R. Corey, Chief, Educational Programs Staff; Mr. J. P. Claybourne, Chief, Sciences, Technology and Applications Office; Dr. James Ragusa, Chief, Operations and Analysis; and Ms. Jeanette Gervin, Physicist, Earth Resource Studies for their involvement in this project. It is certainly an excellent example of interagency cooperation with the result being a fresh approach to science education for students.

This approach to education will keep our students abreast of the changing world of science and will provide them with more meaningful experiences.

Sincerely,

R Blubaugh

Robert L. Blubaugh
Superintendent

cc

FOREWORD

National Aeronautics and Space Administration

NASA has conducted a program in elementary and secondary education since its creation as an executive agency in 1958. We have made available to teachers and the whole of the educational community the results of NASA's research and development efforts in aeronautics and space.

There was an atmosphere of adventure and excitement in the agency's early days as we looked toward the unknown. Bold new steps into the unknown compelled us to develop bold new technologies, new techniques finding increasing application right here on Earth.

In the late 1960s, there developed a new concern about our own small planet. We became more aware of our polluted land, oceans and atmosphere. We became more aware of mineral and energy shortages. We became more aware of unwise land and water management practices.

Today, an increasing number of NASA programs are oriented toward "problem-solving." Weather, communications, navigation and resources satellites have produced notable accomplishments.

The resources satellites are helping us to manage our farmlands and natural resources. They are helping government and private industry locate new sources of minerals, energy and water. We can now gather up-to-date information useful in land use management. The system provides assistance in the early detection of pollution sources.

All of these NASA programs provide a direct service to us here on Earth. The Space Transportation System of the reusable Space Shuttle era will soon add to our flexibility in the near-Earth study of our space environment and opens up broad areas for developing newer and even more useful technology.

We have been most pleased to have been able to share the resources of the Kennedy Space Center with the School Board of Brevard County, Florida, during the development of this pilot project "Remote Sensing and the Earth."

We believe that this exciting material will encourage educators and students to explore the many broad new avenues suggested by this project.

Lee R. Scherer

Lee R. Scherer
Director
John F. Kennedy Space Center, NASA

We are indeed pleased and proud that the NASA Kennedy Space Center's science and educational programs staffs assisted the Brevard County Schools in preparing this curriculum supplement, Remote Sensing and the Earth. Its use places the County in the front rank of the Nation's schools, which conduct programs in environmental education. To our knowledge, this curriculum guide is the only secondary-school oriented instructional tool that deals directly with significant Landsat investigations, investigations which may point the way for our nation to solve its Earth resources problems.

We congratulate the Brevard County Board of Education's leadership and its instructional staff, particularly Mr. Craig Brosius, for developing for its schools this significant teaching aid.

Frederick B. Tuttle
NASA Headquarters
Director of Educational Programs

ACKNOWLEDGMENTS

The School Board of Brevard County is deeply indebted to NASA and especially Lee R. Scherer, Director, John F. Kennedy Space Center; J. Phillip Claybourne, Chief, Sciences, Technology, and Applications Office; Dr. James M. Ragusa, Chief, Earth Resources Operations and Analysis; and Mr. Raymond R. Corey, Chief, Educational Programs Staff for making their resources available to help in the development of this document.

Dr. Luther Rogers, former Superintendent of Brevard County Schools, and John N. Forbes, Assistant Superintendent for Finance, are also greatfully acknowledged for their support of science education. Through their efforts, Craig A. Brosius, Science Resource Teacher, was made available as a co-investigator at the Kennedy Space Center to participate in this innovative science education task with Janette C. Gervin and Dr. James M. Ragusa of NASA.

Through this unique combination of the scientific/user community and the academic world, senior high school teachers and students have available recent and relevant applied ecological science material.

Special recognition goes to the investigators whose articles were used in unedited form in Section Two of the document, and to the American Society of Photogrammetry for allowing protions of the Manual of Remote Sensing glossary of terms and other periodical material to be used.

A special acknowledgement to Ms. Carol Shehadeh for providing professional editorial services without which this document would not have been complete.

Finally, we wish to acknowledge Vicki Henry of NASA and Mary Motta of the Brevard County School System for their assistance in typing draft and final material.

FOREWORD

The expressed purpose of this document is to enable senior high school students to study remote sensing technology and techniques as they apply to the ecological sciences. The information presented is in "near real time." The document will, therefore, never be finished, and in the context of our everchanging ecological needs, study and research can never be complete.

Throughout this document a basic idea evolves--space and the view of Earth from higher elevations has and will provide the perspective needed for many ecological problem solutions. This synoptic view is an ideal location from which to observe, monitor, and hopefully better understand our global systems. This broader perspective has been made possible to a great extent by the space program of the United States, which continues to provide an ever increasing variety of down-to-earth benefits for mankind. Earth resources and weather satellites have provided a new visibility to investigators as well as to the public. Without early manned space flights, we might never have realized how delicately balanced and interdependent our Spaceship Earth's environmental systems are.

This document will greatly enhance student understanding of how ecological science remotely acquired data are obtained, analyzed, and used. Significantly, exposure to current and practical applications by a variety of investigators is provided. It is intended that the student be able to comprehend advanced scientific technology by applying various physical science concepts to biological science study problems. To accomplish this, a scientific interdisciplinary approach to learning is necessary.

In summary, Remote Sensing And The Earth is a specially designed reference which discusses methods of studying some of today's ecological problems which directly or indirectly affect us all. Through the use of this document, expanded insight will be developed into this relevant area of global concern.

ORGANIZATION OF MATERIAL

Section One material, for the most part, is "state-of-the-art." Included is a brief description of how earth resources remote sensing technology has historically evolved and what applications to ecological studies have been found. In addition, information is presented about the nature of light, of remote sensors and their platforms, and of how remotely sensed data are analyzed. Because of the nature of this material, it is essential that students develop a working knowledge of this important part of the document.

Section Two is composed of carefully selected readings which report formal research which has been accomplished by principal investigators. Several hundred articles were reviewed before the present list of sixteen was finalized. This section includes two to three articles for each of the following discipline areas: agriculture, land use, geology, water resources, marine resources, and the environment. These papers represent current research by investigators who use the latest available techniques to obtain and analyze data using the scientific method applied to problem solving. All articles are presented without revision except for retyping into a standard format.

Section Three consists of fundamental laboratory excursions intended to introduce the student to a variety of lab projects. Through these projects, the student will discover first hand map reading and analysis, certain characteristics of the visible spectrum, and other areas relevant to remote sensing applications. These laboratory activities were developed to serve as a "starter set" for both students and teachers. Many other learning experiences are, of course, possible and are encouraged.

The Appendix, the final section of this document, contains numerous supplemental references. This material has been included because of the limited reference material normally available to most students. Because of its content and inclusion, the document is essentially self-contained and complete for most classroom applications.

SECTION ONE

THE BASICS OF REMOTE SENSING

A BRIEF EVOLUTION OF REMOTE SENSING — Page

Traces significant early developments of remote sensing as well as important contributions of the space program. 2

APPLICATIONS TO EARTH RESOURCES

Discusses applications of remote sensing technology to such diverse areas as agriculture, range, and forestry; land use; mineral resources; water resources; marine resources; and the environment. 10

THE NATURE OF LIGHT

Presents basic information about the Sun, what light is, and the atmospheric effects on light transmission. 18

REMOTE SENSORS

Briefly describes a variety of photographic and non-photographic sensors which are used for remote sensing purposes. 26

REMOTE SENSING PLATFORMS

Examines the multitude of remote sensing platforms including surface observations, balloons, various aircraft, spacecraft, and satellites. 42

THE ANALYSIS OF REMOTELY SENSED DATA

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   Describes how LANDSAT data are used to economically monitor California grasslands for better livestock management.

2. UTILIZATION OF LANDSAT IMAGERY FOR MAPPING VEGETATION ON THE MILLIONTH SCALE, by Donald L. Williams and Jerry C. Coiner. 102

   Examines the feasibility of using LANDSAT imagery to develop world vegetation maps in conjunction with a UNESCO classification system.

LAND USE

3. CHANGE IN LAND USE IN THE PHOENIX (1:250,000) QUADRANGLE, ARIZONA, BETWEEN 1970 AND 1973: ERTS AS AN AID IN A NATION-WIDE PROGRAM FOR MAPPING GENERAL LAND USE, by John L. Place. 117

   Demonstrates the use of satellite imagery to revise existing land use maps outdated because of new residential developments, croplands, and reservoir fill-up during a period of dynamic growth in Phoenix, Arizona.

4. IMPROVED RESOURCE USE DECISIONS AND ACTIONS THROUGH REMOTE SENSING, by R. Hill-Rowley, M. Boylan, W. Enslin, and R. Vlasin. 147

   Relates the applications of remote sensing to various needs of government agencies and private organizations for the purpose of assisting decision-makers responsible for actions concerning resource users. Seven case situations are presented.

5. PHOTOARCHAEOLOGY, by Carl H. Strandberg. 172

   Discusses the use of a variety of films in detecting pre-Columbian archaeological sites in South Dakota.

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6. APPLICATION OF COMPUTER PROCESSED MULTISPECTRAL DATA TO THE DISCRIMINATION OF LAND COLLAPSE (SINKHOLE) PRONE AREAS IN FLORIDA, by A. E. Coker, R. Marshall, and N. S. Thomson. 181

Explains how certain remotely sensed data can be correlated to study the sinkhole phenomena in the Bartow, Florida, area.

7. LANDSAT DATA: A NEW PERSPECTIVE FOR GEOLOGY, by Ralph N. Baker. 194

Describes the use of LANDSAT imagery for varied geological studies over large areas.

8. ACTIVE AND INACTIVE FAULTS IN SOUTHERN CALIFORNIA VIEWED FROM SKYLAB, by P. M. Merifield and D. L. Lamar. 205

Presents results of high resolution photographic analysis of land faults in earthquake-prone southern California.

WATER RESOURCES

9. OPTICAL DATA PROCESSING AND PROJECTED APPLICATIONS OF THE ERTS-1 IMAGERY COVERING THE 1973 MISSISSIPPI RIVER VALLEY FLOODS, by Morris Deutsch and Fred Ruggles. 226

Illustrates the timely use of satellite imagery to prepare Mississippi River flood maps for regional planning and disaster relief purposes.

10. APPLICATIONS OF ERTS-1 IMAGERY TO TERRESTRIAL AND MARINE ENVIRONMENTAL ANALYSES IN ALASKA, by D.M. Anderson, H.L. McKim, W.K. Crowder, R.K. Haugen, L.W. Gatto, and T.L. Marlar. 245

Concerns the method of identifying and monitoring estuarine surface water circulation patterns and changes at different Alaskan sites.

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11. WATER-MANAGEMENT MODELS IN FLORIDA FROM LANDSAT-1 DATA, by A. L. Higer, E. H. Cordes, A. E. Coker, and R. H. Rogers. 273

Describes the use of ERTS-1 as a near real-time data-relay system for south Florida water quantity and quality monitoring. Also presented is an ecological model of the Shark River Slough in Everglades National Park.

MARINE RESOURCES

12. COASTAL PROCESSES, by Robert Dolan and Linwood Vincent. 305

Presents results of an investigation of crescentic features of sandy coasts using high altitude aerial photography.

13. MONITORING COASTAL PROPERTIES AND CURRENT CIRCULATION WITH ERTS-1, by V. Klemas, M. Otley, C. Wethe, and R. Rogers. 315

Reports results of the use of recurring ERTS-1 data to study various water parameters in Delaware Bay.

14. A FEASIBILITY DEMONSTRATION OF AERIAL PHOTOGRAPHIC SUPPORT FOR MARINE ARCHAEOLOGICAL SURVEYS, by A. D. Marmelstein. 341

Demonstrates the use of remote sensing to locate shipwrecks in the Florida Keys using selected films and filters for improved water penetration.

THE ENVIRONMENT

15. THE MAPPING OF MARSH VEGETATION USING AIRCRAFT MULTISPECTRAL SCANNER DATA, by M. Kristine Butera. 351

Illustrates the application of aircraft multispectral scanner data in identifying and mapping Louisiana marsh vegetation species for salinity zone determination.

16. SOLID WASTE AND REMOTE SENSING, by Donald Garofalo and Frank J. Wobber. 372

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SECTION ONE

THE BASICS OF REMOTE SENSING

FOREWORD

This section is concerned with remote sensing technology as it relates to earth resources applications. In its broadest sense, remote sensing refers to the collection of data about an object from a distance without actual physical contact. Thus, seeing a plane, hearing a song, or feeling the rumble of a train is included in this definition. Since early time, people have sought to extend their sensory abilities. Sharper vision, better vantage points, looking glasses, and other means have been employed in their search for information.

In the last century and a half, mechanical and electronic devices have been added to the collection of methods for supplementing man's senses. Cameras and scanners have used special light-sensitive materials to record for posterity things people could not remember or see or discern. These instruments have detected the radiant energy reflected or emitted by objects under investigation. This gave rise to the narrower definition of remote sensing as well as the coining of the term. Now remote sensing describes the collection of information about physical phenomena from a distance using special devices.

Why is remote sensing used? An important reason is that in order to find the best solutions to our planet's problems, the best possible information is needed. Remote sensing provides a synoptic view of areas which are often inaccessible. These areas may be seen in 'colors" beyond the range of the human eye. The scene can be recorded at one instant, is permanently stored, and is often more useful than traditional methods of survey.

While the remote sensing process is complicated, basically it begins when light from the Sun is altered as it travels through the atmosphere of the Earth, strikes the surface, and is reemitted toward space. This transformed energy is collected by a sensor mounted on a platform which may be many miles above the Earth's surface. The resulting data are then analyzed to extract the desired information. This new knowledge is then applied to a wide variety of problems encompassing many fields of study.

SECTION ONE

THE BASICS OF REMOTE SENSING

A BRIEF EVOLUTION OF REMOTE SENSING

Early Developments

In 1839, two Frenchmen, Daguerre and Niepce, took the first photographs. These photographic plates used sodium thiosulfate crystals and had to be developed immediately. The new technology was put to a variety of uses. In the 1840's, photographs were used in topographic mapping. These photographs were scaled using the same methods that had earlier been applied to hand-drawn sketches. In the late 1850's, the balloon flights over Paris, France, and Boston, Massachusetts, produced pictures of buildings and harbors "as seen by the eagle and wild goose," in the words of Oliver Wendell Holmes. Meanwhile, photographers recorded the sights while on expeditions to explore the American West. In the Civil War balloons were used for military reconnaissance, with human observers sighting and mapping the enemy. After the war, the silver halide emulsion was produced. This allowed photographic plates to be developed at a later time and separated the camera from the developing equipment. Since the developing equipment no longer had to be part of the camera system, the use of cameras on kites and rockets was introduced.

By the turn of the century, three-color light separation had been achieved using a multiple lens camera. The spectral range of photographs was extending into the invisible light beyond red and violet, primarily for use in astronomy. Multispectral cameras, stereoscopic analysis equipment, and panoramic cameras were introduced in the first decade of the twentieth century. Radar (the Radio Detection and Ranging System) was tried in ship navigation (1903), and Wilbur Wright photographed a small Italian town from an airplane (1909). During World War I, Royal Air Force Lieutenant Laws, after considerable discussion, convinced his superiors to try photographing the enemy from airplanes. By the end of the war, thousands of photographic prints were being processed each night. Camouflage and photointerpretation were becoming important military activities.

In the 1920's, multiple layer color film was developed and aerial survey companies were organized. Aerial photography was first applied to petroleum exploration, and radar was proposed for detecting enemy ships and planes. In the next decade, a number of government agencies including the Geological Survey, Department of Agriculture, Forest Service, Navy, and the Tennessee Valley Authority adopted the use of aerial photography.

Research into remote sensing principles expanded during World War II. Germany entered the war with an excellent photo reconnaissance organization. The Germans were able to plan rapid and efficient military advances, but others were to learn the value of remote sensing. After being cut off from their land sources of intelligence by the retreat from Dunkirk, the British had to rely increasingly on aerial photography. In 1940 the aerial photographs showed the German military buildup for an invasion of England. Realizing that the attack was imminent, the RAF launched a massive bombing mission and averted the invasion. Since the 1930's radar had been under development in Britain, Germany, and the U.S. During the war it enabled RAF fighters from inland bases to locate and attack enemy bombers over the English Channel.

While war raged in Europe, the U.S. Army Air Corps, at the urging of General George Goddard, was exploring the development and use of infrared film. Major advantages of this film were improved haze penetration and camouflage detection. Like Japan and Russia, the United States entered the war with little photo reconnaissance capability. Some military commanders were unfamiliar with and somewhat wary of the new techniques. However, as the conflict continued, American aerial reconnaissance improved. It concentrated on the location of supply lines, the detection of camouflage, and the estimation of water depths--particularly along possible beachheads. By contrast, photo-intelligence declined in Germany following the death of its leader, General Werner von Frisch.

The war effort thus stimulated research into remote sensing principles, systems, and targets which supported both military and civilian uses in the post war era. Work on infrared films and the spectral properties of camouflage and natural cover proved useful in the study of plant diseases in the 1950's. In addition to detecting ships and planes, radar explored the effects of wind and waves on the oceans. It examined weather in the troposphere, the composition of the upper atmosphere, and the surface and motion of the Sun, Moon, and planets.

Multispectral techniques were used to produce the first color movies in the late 1940's. In the early 1960's, they were incorporated into complex multilens cameras for military uses and terrain analysis.

The Contributions of the Space Program

In 1946 photographs of the Southwestern U.S. were taken from V-2 rockets. They indicated the potential of high altitude remote sensing. By 1960 Tiros (Television Infrared Orbiting Satellite) I, the first meteorological satellite, was used to observe the infrared emission of the Earth from orbit. Tiros, Nimbus, and ESSA (Environmental Science Services Administration) satellites followed. They recorded cloud patterns, weatherfronts, hurricane formations, snow, ice, surface temperature, and humidity profiles. Sensors in the visible range were added to the satellites and the resolution in the infrared was improved. The results became part of the evening news and weather.

Mercury missions in the early 1960's photographed the oceans and geologic formations of the Sahara Desert and Himalayan Mountains (see Figure 1). Although originally intended for geological investigations, these images excited interest in the resource evaluation possibilities of remote sensing. As a result, Gemini astronauts took 1100 color photographs in the middle 1960's. One example is Figure 2 which shows the vegetation patterns in California's Imperial Valley south of the Salton Sea, as well as turbidity plumes in the sea itself. These photographs have also been used in studies of volcanoes, tectonics, geologic forms, oceans, and rivers. Discovered was the fact that wind rather than stream erosion had shaped the formations of the Sahara and that the Agua Blanca fault on the Baja Peninsula moved only locally--not along its entire length.

The early Apollo missions of the late 1960's carried conventional multispectral and multilens cameras with many film and filter combinations. Apollo photographs like that of the Georgia coast (Figure 3) have been used for coastal and terrain

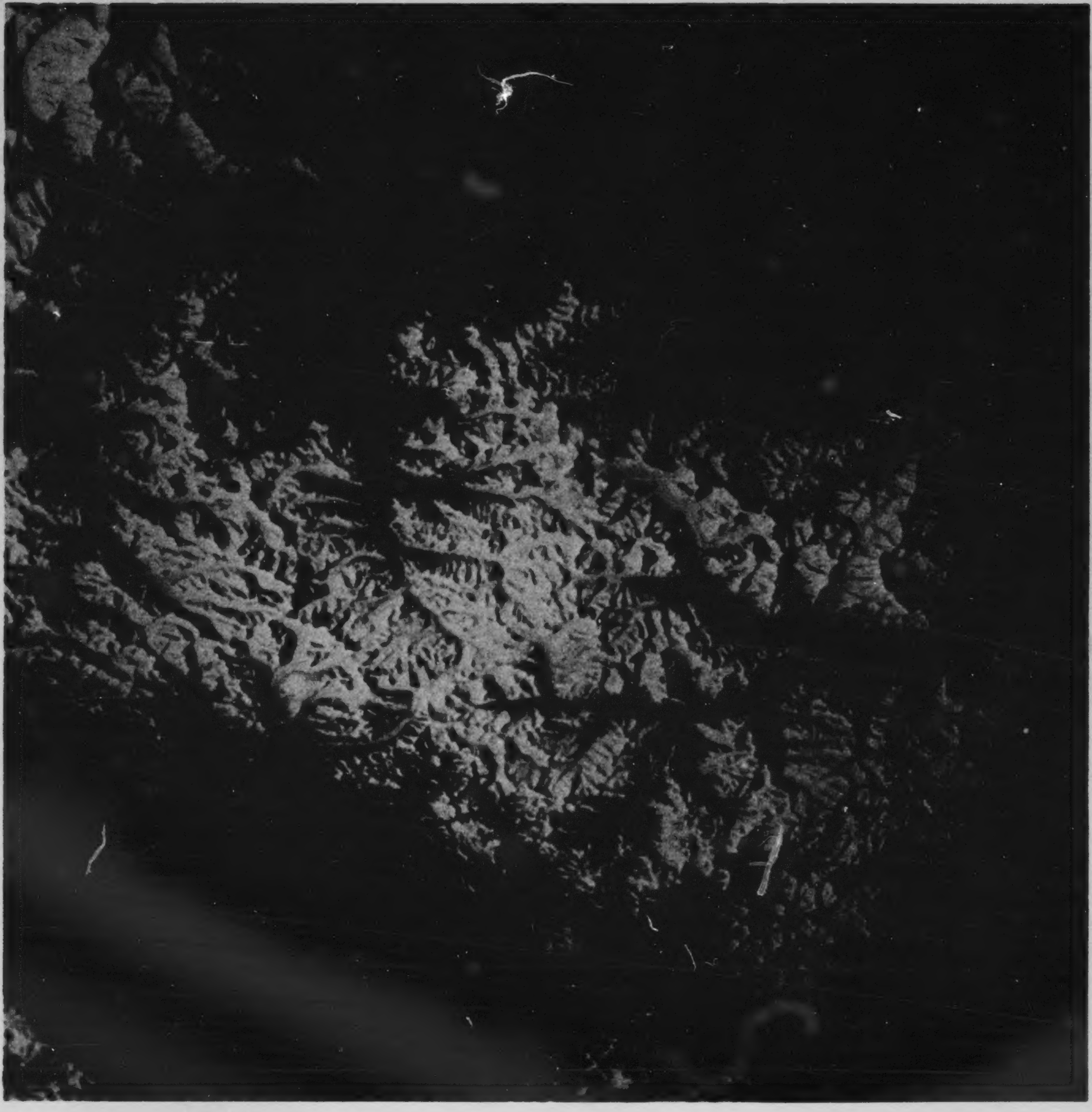

Fig. 1 A Mercury photograph of the Himalayan mountains in central Asia.

Fig. 2 A Gemini photograph of the Salton Sea and Imperial Valley in California (looking southeast).

Fig. 3 A color IR photograph of the Georgia coast taken by one of the Apollo 9 astronauts.

mapping. Astronauts on lunar missions photographed the Earth from space and from the lunar surface.

The main objective of the Manned Spaceflight Program of the 1960's was landing men on the Moon and returning them safely to Earth. Earth resources investigations which sparked so much interest were secondary. However, as the 1970's began, concern about ecology on Earth was growing. Air and water pollution, the disappearing wilderness, food shortages, and changes in the overall "quality of life" raised serious questions about the future of the planet and the consequences of technological progress. The expeditions to the moon increased this awareness with photographs showing our Earth as a beautiful blue jewel--suspended in the black void of space (see Figure 4). The Earth being seen as a spaceship with limited size and supplies carrying its crew through time became a familiar analogy. The pressure to turn man's knowledge toward the solution of his problems on Earth grew. Thus, a new era began with the application of remote sensing techniques to help solve many earth-bound problems.

The space community recognized the possibility of applying its lunar technology to earthbound problems. When detailed earth resources experiments were resumed by the Skylab teams in 1972, remote sensing was applied in every earth science discipline. So many data were gathered that analysis and complete study would require many years.

In that same year, the first Earth Resources Technology Satellite (ERTS--now renamed LANDSAT) was launched from California. Thousands of scientists from many nations participated in programs to utilize the multispectral images provided by LANDSAT. Among the numerous projects, geological faults were mapped in California and Wyoming. The effect of industrial and municipal dumping was traced off the New Jersey coast and in Lake Champlain. New mineral deposits were sought in South Africa.

By 1975, when the second LANDSAT was launched, Canada, Italy, Japan, and Brazil were making preparations for their own LANDSAT receiving stations. NASA was planning a SEASAT for the oceans. A LANDSAT with a thermal channel was being designed, and scientists were planning earth resources experiments to be flown on the Space Shuttle.

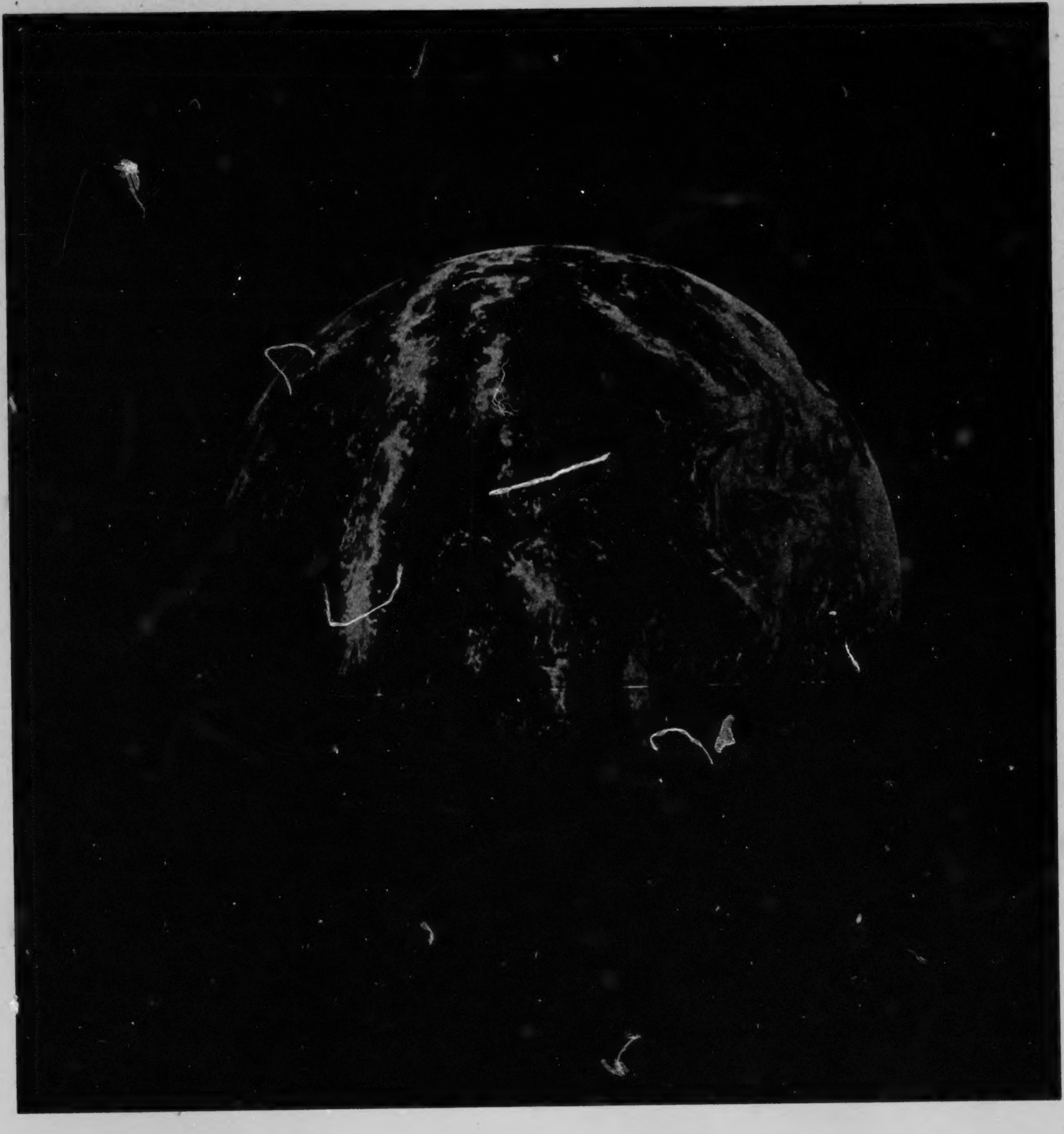

Fig. 4 An Apollo 11 photograph of the Earth from space.

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A BRIEF EVOLUTION OF REMOTE SENSING

Vocabulary - Define the following terms in detail.

Remote Sensing
Light
Sodium Thiosulfate
Silver Halide
Camouflage
Multispectral
Photo Interpretation

Reconnaissance
Radar
Signature
Infrared
LANDSAT
Sensors

Questions - Answer the following inquiries in detail.

1. Discuss the improvements in remote sensing over the last 150 years.
2. Why is remote sensing important?
3. Discuss light energy in relation to sensors.
4. Explain the contribution of Daguerre and Niepce to remote sensing.
5. What did R.A.F. Lieutenant Laws accomplish?
6. Who was General Werner von Frisch?
7. What contributions did satellites make to remote sensing?
8. Discuss the contributions of the Mercury, Gemini, and Apollo programs.

Since 1971, the U.S. Government has made a concerted effort to explore the possibilities of using remote sensing for identifying and managing earth resources. These techniques have been applied in many disciplines including biology, geography, geology, hydrology, oceanography, and ecology. Pure research has been pursued to increase our understanding of the basic principles involved in remote sensing. Other studies have applied these principles to problems on Earth. These applications have in turn contributed new observations to the theory of remote measurement. The broad overview of remote sensing applications provides examples of past attempts and achievements as well as a promise of future potential.

Agriculture, Range, and Forestry

The biological applications of remote sensing can be divided into four basic areas of study: agriculture, range, forestry, and wildlife habitats. The last of these topics will be examined under environment. The study of living plants is one of the most complicated areas of remote sensing because a number of factors influence the color and texture of crops observed on aerial and satellite imagery. These include: leaf size, shape, age, structure, and pigments; amount of water, salt, nutrients, and shade; distribution of branches, leaves, and flowers; planting pattern and season; and ground cover and moisture. The use of color infrared film or multispectral scanner imagery from several dates in conjunction with regional crop calendars enabled photointerpreters to identify many crops.

A predicition of the harvest from remotely sensed crop maps would aid the nation's agricultural planning, economic position, and world trade negotiations. These crop yield forecasts are even more difficult to perform than crop identification because they require a knowledge of crop acreage and yield per acre. The likelihood of weather and disease damage to the growing plants before harvest must also be included. In an attempt to account for these factors, scientists have examined the appearance of crops and attempted to discover measurements that could be related to plant productivity. These techniques have been combined in a NASA effort to produce the first world-wide yield forecast for a major crop (wheat) done by remote sensing.

Because only about 10 percent of the Earth's land surface is now under cultivation and less than 11 percent of the remaining land is arable, the total possible world harvest is limited. It is also estimated that from one-third to one-half of the planted crop is destroyed each year by diseases, insects, floods, and storms. If some of this loss could be prevented, more food could be produced on the same amount of land.

Remote sensing provides a rapid assessment of flood and storm damage. It may also improve our understanding of the behavior of these phenomena. In the field of disease and insect control, photointerpretation can also serve a beneficial role in the detection and prevention of crop damage. Diseases and other forms of stress in plants are indicated by such symptoms as color changes, defoliation, and crown distortion. These symptoms can be detected over large areas remotely. Moreover, since discoloration appears first in the infrared, photointerpreters may be able to detect the disease before ground observers do. This will enable farmers to remove infested plants early and to localize and schedule their applications of pesticides effectively.

Particular success has been achieved in controlling southern corn leaf blight.

Remote sensing of range land is primarily concerned with the inventory and monitoring of the range's vegetation, condition, and, on occasion, grazing animals. Increasing economic demands and multiple uses for the same land make the detection of change still more important. Aerial photography and satellite imagery have been used to study seasonal and long term variations in grass and moisture with measurable success.

The use of remote sensing in forest inventory dates from 1887 when a German forester ascended in a tethered baloon to complete his forest mapping. Traditionally, intensive management has been typical of the sustained yield, multiple use forests of Europe. It is now becoming more necessary in this country and with it comes the need for regular inventories. The relatively large physical size of North American forests poses a special problem. It has encouraged the use of remote sensing in forest classification since the 1930's. Using a variety of sensors, foresters describe tree types, species composition and distribution, crown size, and height of the trees. This information is then used to plan logging, reforestation, recreational uses, and overall management.

Remote sensing is also used in assessing and preventing damage. Insects destroy the equivalent of one year's gorwth of lumber in this country each year. Their activities can sometimes be detected on aerial and satellite imagery due to their effect on the infested tree. Fire fighters use aerial photography to detect the extent of the fire, to plan their attack, and to assess damage. Meanwhile, other foresters are using remote sensing to investigate the effects of air pollution on ponderosa pines near Los Angeles. Damage is believed to be caused by ozone, flourides, nitrous oxide, peroxacetyl nitrate, copper oxides, and sulfur dioxide.

Land Use

Aerial photography has been used to develop and update land use maps for parts of Mississippi at a fraction of the cost of conventional methods. Standard keys, spectral characteristics, training samples, and computer classifications are among the techniques now under investigation. Satellite imagery may prove more useful in rural areas where scales of change are normally larger. Urban planners need a method for monitoring the rapid growth of the complex areas they must manage. While aerial photography can provide a valuable tool in this effort, satellite imagery will probably require greater resolution for many urban applications.

Present land use patterns and growth trends revealed in remote imagery serve as a basis for land management and planning. Certain types of improper or illegal land use can be detected and halted, thereby enforcing past management decisions. Remote sensing also has application in specific land use problems. In transportation, aerial imagery can be used to record flow patterns needed for highway planning. Aerial and satellite imagery can reveal such geologic hazards as sinkholes in Florida, geologic faults in California, and underground ice in Alaska. This information is used by engineers to locate future highways.

Remote sensing has also been turned toward man's past land use -- namely archaeology. Ridges from prehistoric cultivation sometimes show up clearly on aerial photographs. Foundations and fill associated with buried construction affect the growth of vegetation due to differences in soil type, depth, and drainage. Hence, ancient cities, fortresses, houses, roads, and burial grounds can often be seen in black-and-white and color infrared aerial photography. The actual archaeological remains can also be sought. One example is the search for Spanish shipwrecks in the Florida coral reefs.

Mineral Resources

Black-and-white aerial photographs have been used for some time in geological and mineral exploration. The synoptic view aids in the identification of structures and landforms that may cover large areas or cross state borders. Color photography frequently provides more information. The use of stereo techniques, low sun angles, and snow cover makes it possible to determine relief. Some of these analysis techniques will be discussed later.

In their search for information about past ages, present conditions, mineral deposits, and petroleum; geologists have used aerial photography extensively. They have detected features of past glaciation in Utah and structural and lithologic characteristics in southern flatlands. Ancient shorelines in California and surface structures along the Alaskan Highway have also been observed. Since mineral deposits are often found at the intersections of structural features like faults, aerial and satellite analysis of linears can narrow the search considerably. In a similar manner, petroleum is trapped under domes and anticlines, which can sometimes be mapped from the air and space. The relation between known finds and surface features observed from altitude may also improve the probability of discovering new ore and oil deposits.

Multispectral techniques have been applied to locating iron-bearing minerals and to geobotanical and lithologic mapping. Extensive investigation on the surface is required for geobotanical work. A number of remote sensors must usually be combined to differentiate rock types.

Thermal imagery was used to examine Surtsey Volcano off southern Iceland in 1966. In 1968 similar imagery revealed a geothermal heat source in the island's interior. The circum-Pacific volcano belt does experience a higher heat flow than does the rest of the world. Some volcanoes have exhibited thermal precursors of eruptions. Unusual heat flows are also sometimes associated with ore deposits. Thermal imagery has been used to detect massive blocks of ice, potential hazards to construction, concealed in the Alaskan permafrost. Another geologic hazard, the complex of fault systems and fracture zones in southern California, has been mapped on thermal imagery. This information can be added to lineament maps from aerial photography and satellite multispectral imagery. These improved maps can then be studied to increase our understanding of earthquake processes and global tectonics.

Since radar is sensitive to characteristic fault features like relief, rock alteration, and ground water, it can also detect faults quite well. It often reveals joints, folds, and geomorphic features. Some of these structures are associated with certain types of ore deposits, glacial features, and drainage.

In certain local areas, including a tideland region of Louisiana and a mountainous district of Colorado, remote sensors have been used to examine, identify, and map local geologic features. Multisensor approaches have also been found more effective than single sensors in classifying rock types and identifying rock composition.

Water Resources

In hydrological studies, remote sensing has been applied to lakes, marshes, and swamps. Color infrared film and multispectral scanner images have been used to study water color and aquatic vegetation. Spectrometers and lasers have been used to analyze the chemical composition of water. Surface temperature, one of the simpler remote sensing measurements, can be recorded thermally. A number of photographic film and filter combinations and scanner wavelengths have been tried to achieve greater depth penetration in water. The results of these studies will provide a better understanding of hydrological and hydrobiological systems and will furnish a more complete record of the present state of these water bodies. It will also provide a means for detecting, monitoring and controlling deterioration, particularly that precipitated by pollution, for better water management.

Conservation of water resources is another important part of water management. A knowledge of the water in a drainage basin or channel network now and in the near future would be very helpful in avoiding shortages or floods. Efforts are now underway to incorporate synoptic remote measurements into mathematical descriptions of drainage basins. Aerial and satellite imagery can also reveal the results of hydrodynamic forces in many parts of the world by monitoring natural and man-made alterations in stream channels, rivers, and lakes which might require intervention. The effect of urbanization on the natural watershed and its run-off is another area of hydrologic interest where remote sensing is contributing to a better understanding of the conditions.

One of the sources of water for northern drainage systems, the spring snowmelt, sometimes unleashes too much water too fast, resulting in flooding. For this reason, scientists are developing a method using satellites for estimating the amount of snow cover and snow mass. But in order to accurately predict the rate of snowmelt, they must overcome such problems as cloud cover, snow depth, and the variety and reversibility of factors contributing to snowmelt.

Another freshwater source is ground water discharge. Springs flowing into significantly warmer or colder waters have been observed by thermal scanner in California's Mono Lake and off the Atlantic and Gulf coasts of Florida. Off the north shore of Jamaica, springs flowing from a limestone aquifer may be located by temperature alone. On the south coast springs flowing from a sand and gravel aquifer transport a cloud of debris, which can be seen on conventional film. Aquifers are also studied by temperature and lineaments for well siting and for safe construction. It is, however, the contribution of ground water to stream flow that particularly interests the water manager. Discharge and loss in streams have been studied on aerial photographs in Arizona, by radar in Missouri, and by observation of ice in northern Michigan. The flow of ground water into streams must be included in the hydrological models for water management and flood prediction.

Once a flood has occurred, remote sensing can be used to map the extent of inundation for disaster relief. Even after the flood crest has passed, vegetation damage, wet soil, and "shorelines" on snow will indicate the extent of flooding on remote imagery. It is believed that locating soil or vegetation types associated with periodic flooding may enable investigators to map flood plains, thereby predicting flood-prone areas. This could provide a standard to support better management of these areas.

Marine Resources

The immense size and relative uniformity of the world's oceans make them especially suitable to remote measurement. Wind and sea state (wave conditions) over substantial areas are studied with radar, microwave scanners, and sun reflection in the visible portion of the spectrum. Distributions of sea surface temperatures, including the trace of the Gulf Stream and its eddies, have been observed repeatedly. Sea ice can be detected with radar, while its relative age can be determined with passive microwave systems.

In the visible and near visible range, special attention is given to the movement of water masses in response to currents. Sensors record the chlorophyll, algae, and sediment associated with these masses. The spread of effluents, oil slicks, and thermal discharges has also been studied. Bathymetry, which received considerable emphasis during World War II, still requires extensive effort to go beyond calm, clear waters of moderate depth.

Because the nearshore marine environment is quite complex, it offers a variety of study areas. Coastal currents can often be detected in the thermal and visible range for placement of structures and improved erosion control. The circulation of municipal and industrial wastes, agricultural run-off, construction debris, thermal discharges, and oil slicks within estuaries has been studied extensively through remote sensing. Aerial and space photographs and multispectral and thermal images of estuaries were supported by surface observations. The mixing of river plumes with the ocean can be studied in the infrared and thermal. The changes due to sedimentation and erosion at river mouths can be detected in the visible and near infrared. This type of information can be important to navigation, harbor construction, and coastal zone management in general.

The legal boundary associated with mean high tide is another important parameter for coastal zone management. The high tide line often determines the portion of wetlands and water in the public domain. An objective standard for locating it would support the efforts of coastal states and territories to preserve these areas. Along open shorelines the high water mark may be recorded by remote sensors on a number of dates and then averaged. On vegetated coastlines characteristic species composition and condition, soil, slope, and other factors must also be used. Vegetation distribution and vigor and specific marshland problems, like dredging and filling, can also be monitored on aerial and satellite imagery.

Substantial portions of the marine fishery industry have employed remote sensing for decades. The French were the first to propose spotting fish from an airplane. The Americans implemented it in the tuna and menhaden industries. Biologists have also used aircraft spotting to study the near-surface schooling species, like sardines and whales. The general development of remote sensing is making new techniques available to commercial fishermen. Scientists interested in conservation of ocean fish, mammals, and invertebrates can also employ these methods. While the fishery industry often uses human observers to distinguish schooling species by their behavior, texture, and color, low-altitude photographic imagery can provide relative distribution and abundance of ocean fish over large areas. Bioluminescence is the light radiated when multitudes of dinoflagellates are jostled by swimming fish. This effect can be used to detect schools from airplanes using special night vision devices developed for the Vietnam conflict. These light intensifying devices, first used on a ship in 1968 and on an airplane in 1971, are more effective in warmer water. They have successfully located menhaden, Spanish mackerel, sardines, shrimp, and other species in the Gulf, Pacific, and Atlantic.

From satellite altitudes, fish schools cannot be observed directly. In fact, most fish spotting airplanes fly between 150 and 950 meters (492 and 3116 feet) and seldom over 3000 meters (9840 feet). Any satellite detection of marine organisms would have to rely on indirect methods to identify factors which could be related to fish schooling. Although sparse surface data and the likelihood that several parameters are involved have made this effort difficult, it has already met with some success. Combining catch records and thermal imagery, the albacore tuna off the cost of Oregon were found to prefer the boundary between the warm river plume and cold upwelling ocean water. Salinity, chlorophyll, water clarity, and sea state may also prove to be related to fish location.

The Environment

The study of the quality of the environment and all the interrelated factors contributing to its health is the province of ecology. Remote sensing applied to the environment examines four basic problems: air quality, water quality, land quality, and wildlife habitats.

Aerial and satellite imagery often shows the smoke plumes of highly industrialized regions. The circulation of the emmission can be observed as can its environmental effects. Examples range from condensation of snow clouds around particulates over Lake Michigan to the death of ponderosa pines on the hills above Los Angeles, California. Certain specialized instruments, including lasers and spectrometers, are also employed to measure atmospheric composition and detect the presence of specific pollutants.

Aerial imagery, particularly in the ultraviolet and thermal portions of the spectrum, can detect such specific water pollutants as oil. This imagery can often trace these discharges to their source. Spills in shipping lanes, whether due to accidents, to cleaning or simply to illegal dumping, require fast reaction to enforce regulations. This can be accomplished with aircraft. In addition, leaks from drill platforms and pipelines can be spotted and stopped early. Remote sensing by color infrared film and thermal scanners can monitor the size, severity, mixing, and sources of industrial and municipal discharges. It also monitors land use practices, including improperly controlled farming, logging, mining, and development. These practices may allow mud, acid, and excessive run-off to enter streams and lakes. The discharge of heated water from electric power plants can also be recorded for study on thermal scanner imagery. Pollutants may range from such hazardous chemicals as the acid iron waste dumped off the New York-New Jersey coast to seemingly harmless natural types. Oil seeps, salt water intrusion, fish oil, algae blooms, and red tide are examples of natural pollutants which are now under remote examination. Some natural pollutants can be aesthetically unpleasant or can degrade the value of the environment.

Land development, strip mining, and logging damage the land as well as the nearby waters. Because remote sensing can assess the damage and its effects quickly and economically, it can be used in planning, monitoring, and enforcing the reclamation of this land.

Wildlife and their habitats are another important consideration in the study of land quality. In the census of live animals, both wild and domestic, aerial photography and thermal data are replacing direct visual counting from airplanes. Deer, rodent burrows, and ant mounds are examples.

The overall habitat of wildlife is also under study. The composition of the vegetation and the nature and cause of changes, which may be subtle or drastic, are of particular interest. Floods, fires, oil spills, and species extinction represent dramatic and obvious alterations in the environment. New drainage patterns, drought, minor pollution, and natural succession are milder, though often significant, examples of the same phenomenon. The extent and nature of the damage is revealed in aerial and sometimes satellite imagery. Early detection of the reason for gradual deterioration can prevent further damage. The more obvious factors can be monitored and removed. Remote techniques are of particular interest in the wetlands and coastal marshes, fishery and water-fowl habitats known for their productivity and delicateness. Vegetation classification and change are being studied from New Jersey and Florida to California and Alaska. Some enterprising wildlife managers have used aerial imagery in their overall planning and forecasting and in their enforcement duties. Thus, remote sensing is finding a variety of uses in a multifaceted field.

APPLICATIONS TO EARTH RESOURCES

Vocabulary - Define the following terms in detail.

Biology
Geography
Geology
Hydrology
Oceanography
Ecology
Agriculture
Range Resources
Forestry
Color Infrared
Multispectral Scanner
Photo Interpreters
Crown Distortion
Defoliation
Aerial Photography
Sensors
Spectral Characteristics
Archaeology
Thermal
Spectrometers
Lasers
Fluorescence
Temperature
Bathymetry
Salinity
Chlorophyll

Questions - Answer the following inquiries in detail.

1. Discuss the following disciplines in relation to remote sensing applications: (a) Agriculture, Range, and Forestry, (b) Land Use, (c) Mineral Resources, (d) Water Resources, (e) Marine Resources, and (f) the Environment.

2. Discuss land cultivation as it relates to remote sensing.

3. Explain inventorying

4. How can land use planners use satellite data?

5. Explain the sinkhole phenomenon..

6. How are multispectral techniques used to search out minerals?

7. How do hydrological studies improve our predictions about water?

8. How is lunar high tide associated with marine resources?

9. How do enviromentalists benefit from remote sensing?

The Sun

Astronomers generally believe that long ago a star system exploded in the area now occupied by our solar system. Little is known about this system, but approximately five billion years ago, the gaseous remnants of its explosion began to condense. Small pockets of local condensation became the planets, but the majority of the mass contracted to form one giant body--our Sun. It stablized as an average star, yellow in color and standard in size, with an interior temperature of 16 million°C (25 million°F). The fusion of its interior continued. It provides the light that supports all life on our planet and the radiance detected by most remote sensing devices.

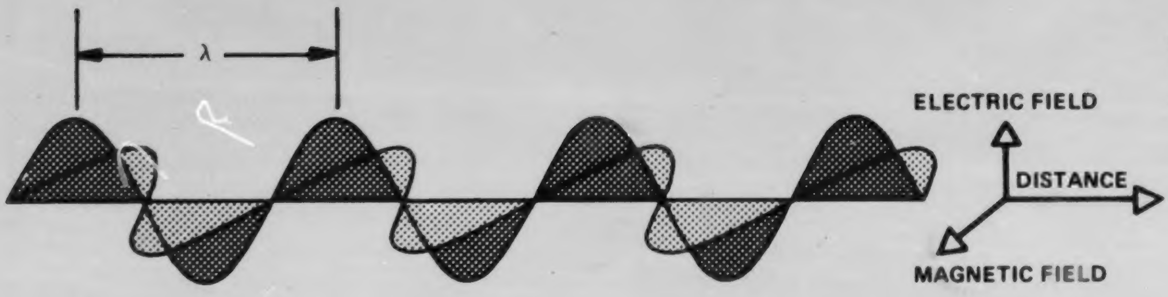
The energy derived from the fusion of hydrogen in the Sun originally produces a barrage of gamma rays, very high energy radiation dangerous to life as it now exists on Earth. Just below the Sun's surface, this radiation is absorbed by the hydrogen atoms. The heat released causes the gas to rise in turbulent motion, expanding as it rises and carrying the energy with it. When this energy arrives at the surface of the Sun, it causes the solar surface to emit light, heats the atmosphere of the Sun to 1 million°C (almost 2 million° F), and sends the solar wind racing toward the planets. The entire journey from the center of the Sun to the surface has taken an estimated 20,000 years, with an additional 8-1/2 minutes required for the light to reach Earth.

Description of Light

Light, which is a form of electromagnetic radiation, can be described in terms of waves and particles. As a wave it is often compared to the waves of the ocean (see Figure 5). Light is pictured as being composed of electric and magnetic fields which oscillate at right angles to the direction of travel. The size of this oscillation is compared to the wave height. The distance between wave crests is referred to as the wavelength. Wave oscillations are called frequency (F) and are determined by the number of oscillations per unit time or number of wavelengths that pass a point per unit time. Also shown in Figure 5 is the relationship between wavelength, frequency (F), and the speed of light (c).

The inverse relationship between wavelength and frequency is also shown in Figure 6. This representation is called the electromagnetic spectrum. Electromagnetic radiation ranges from long wavelength, low frequency radio waves to short wavelength, high frequency gamma rays. Near the center of the spectrum is the narrow band of visible light--the range of the human eye. As should be obvious, the human eye has a relatively limited range of energy perception.

Electromagnetic radiation is the result of motion within atoms and molecules. The wavelength of emitted radiation is related to the energy and type of molecular process involved in its production. The wavelength and energy are inversely proportional. The temperature of a radiating object indicates the amount of energy it has available to stimulate motion within atoms and molecules. So, as the temperature rises, the wavelength of the characteristic radiation drops (see Figure 7). The surface of the Sun, with an average temperature of 6000°K (11000°F), emits radiation which peaks in the visible. This emission spreads across the infrared and to a lesser extent into the ultraviolet. By contrast, the Earth, with an ambient temperature of 290°K (71°F), radiates in the infrared.


λ
ELECTRIC FIELD
DISTANCE
MAGNETIC FIELD

λ = WAVELENGTH
C = SPEED OF LIGHT
F = FREQUENCY

$$F = \frac{C}{\lambda}$$

$$\lambda = \frac{C}{F}$$

Fig. 5 The wave description of light.

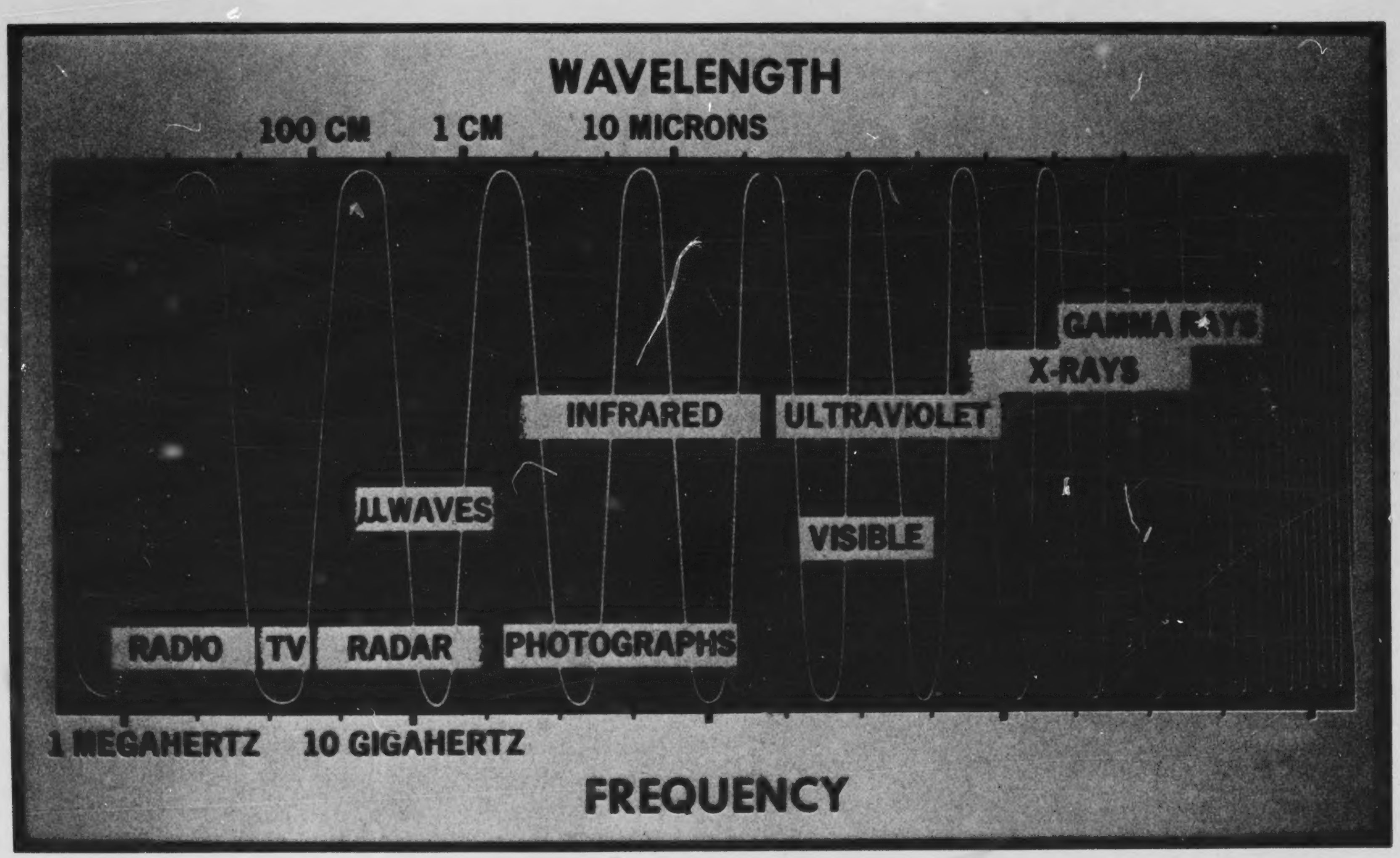

WAVELENGTH
100 CM
1 CM
10 MICRONS
GAMMA RAYS
X-RAYS
INFRARED
ULTRAVIOLET
µWAVES
VISIBLE
RADIO
TV
RADAR
PHOTOGRAPHS
1 MEGAHERTZ
10 GIGAHERTZ
FREQUENCY

Fig. 6 The electromagnetic spectrum.

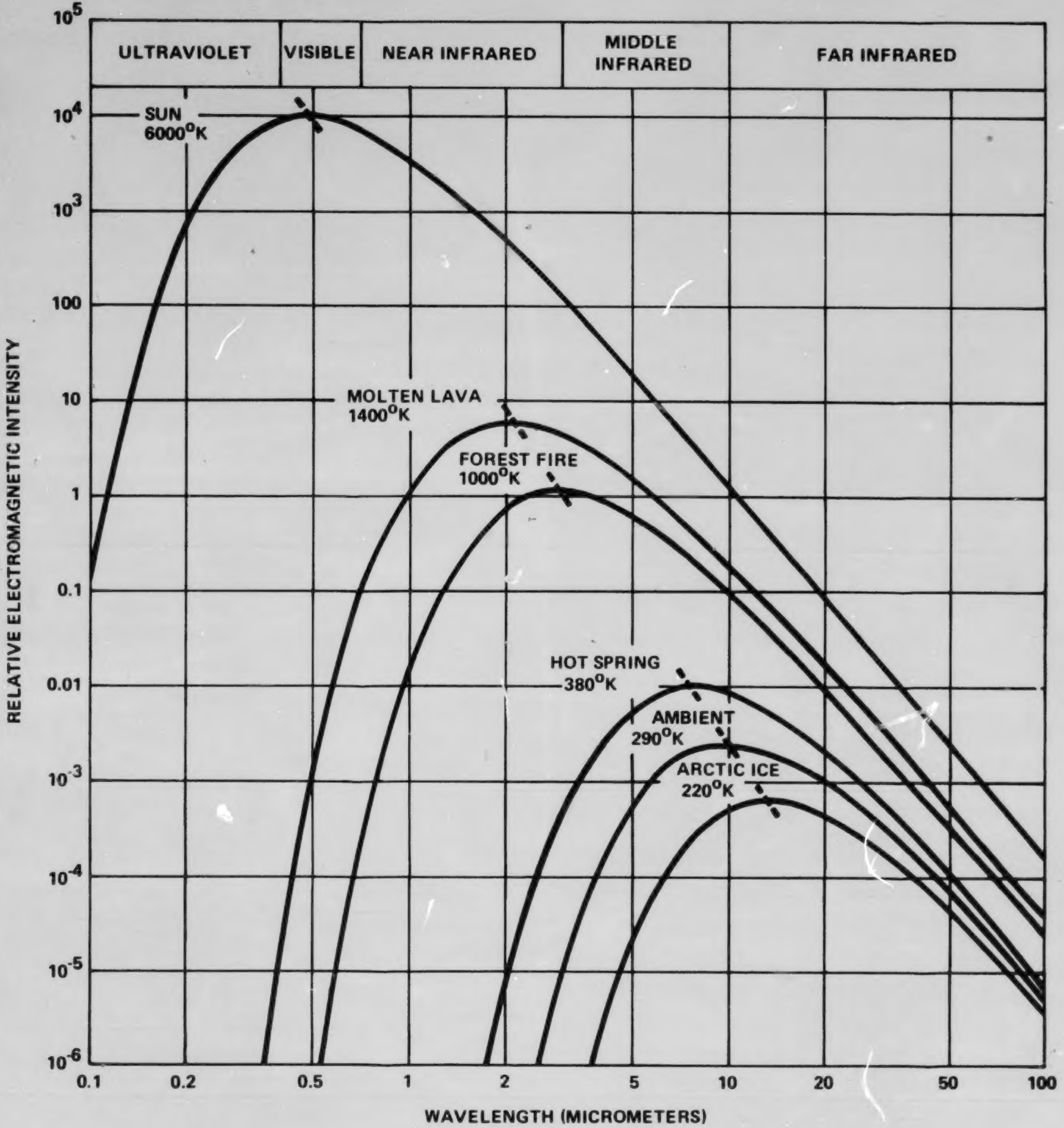


Fig. 7 Electromagnetic radiation emitted by familiar objects at various temperatures.

Since the wave theory does not fully explain the behavior of light, a second complementary description has been developed. The interactions in which light is emitted, absorbed, and reemitted (sometimes at a new wavelength) are often discussed as if elemental particles called photons were being exchanged. Since the internal structure of an atom or molecule determines the size of the photon (i.e., energy) which it can use to change its motion, certain wavelengths of emission and absorption are characteristic of the material responsible. In the atmosphere of the Sun, various cooler gases absorb photons of certain wavelengths, leaving dark bands called Fraunhofer lines (after their discoverer) in the solar spectrum. In much the same way, the constituents of Earth's atmosphere remove portions of the Sun's radiation and make remote sensing at those wavelengths very difficult.

Atmospheric Effects

The solar radiation which strikes the top of the Earth's atmosphere is the strongest source of visible and near visible light in the sky. Reflected light from the full moon comes in a distant second, with one millionth of the Sun's irradiance. Outside the Earth's atmosphere, solar radiation peaks at 0.47 micrometers (green) with 75 percent of the energy at longer wavelengths (yellow, red, and infrared). The amount of solar energy which shines on a unit area at the top of the atmosphere (above 100 km) has been measured and is called the solar constant. Although this quantity has been quite stable in recent times, it does vary with the sunspot activity, and long-term changes in the solar constant might be related to past glacial ages.

Of the solar energy which enters the Earth's atmosphere, only 47 percent is absorbed (and reemitted) at the surface. An additional 35 percent of the Sun's light is reflected back into space from clouds, air molecules, and such highly reflective surfaces as ice and snow. Approximately 18 percent is absorbed in the atmosphere (see Figure 8).

The constituents of the atmosphere modify the Sun's light by scattering as well as by absorption. While some processes like molecular scattering and absorption start high in the atmosphere, processes involving cloud cover and particulates are limited to the lower layer--the troposphere. Together they change the solar spectrum as seen on Earth.

Light striking molecules of nitrogen and oxygen in the atmosphere is scattered more effectively at the shorter wavelengths making the sky blue and the Sun yellow, and shifting the wavelength of maximum intensity toward 0.5 micrometers, the color to which the human eye is most sensitive.

Atmospheric molecules can only absorb light at certain wavelengths. The layer of ozone at 30 km (18 mi) prevents ultraviolet rays with wavelengths less than 0.3 micrometers from reaching the surface, while water vapor and carbon dioxide capture certain bands of incoming solar infrared and upwelling thermal emission from the Earth to produce the so-called "greenhouse effect."

While the condensed water vapor in thick clouds represents a serious obstacle to light at all wavelengths, particularly

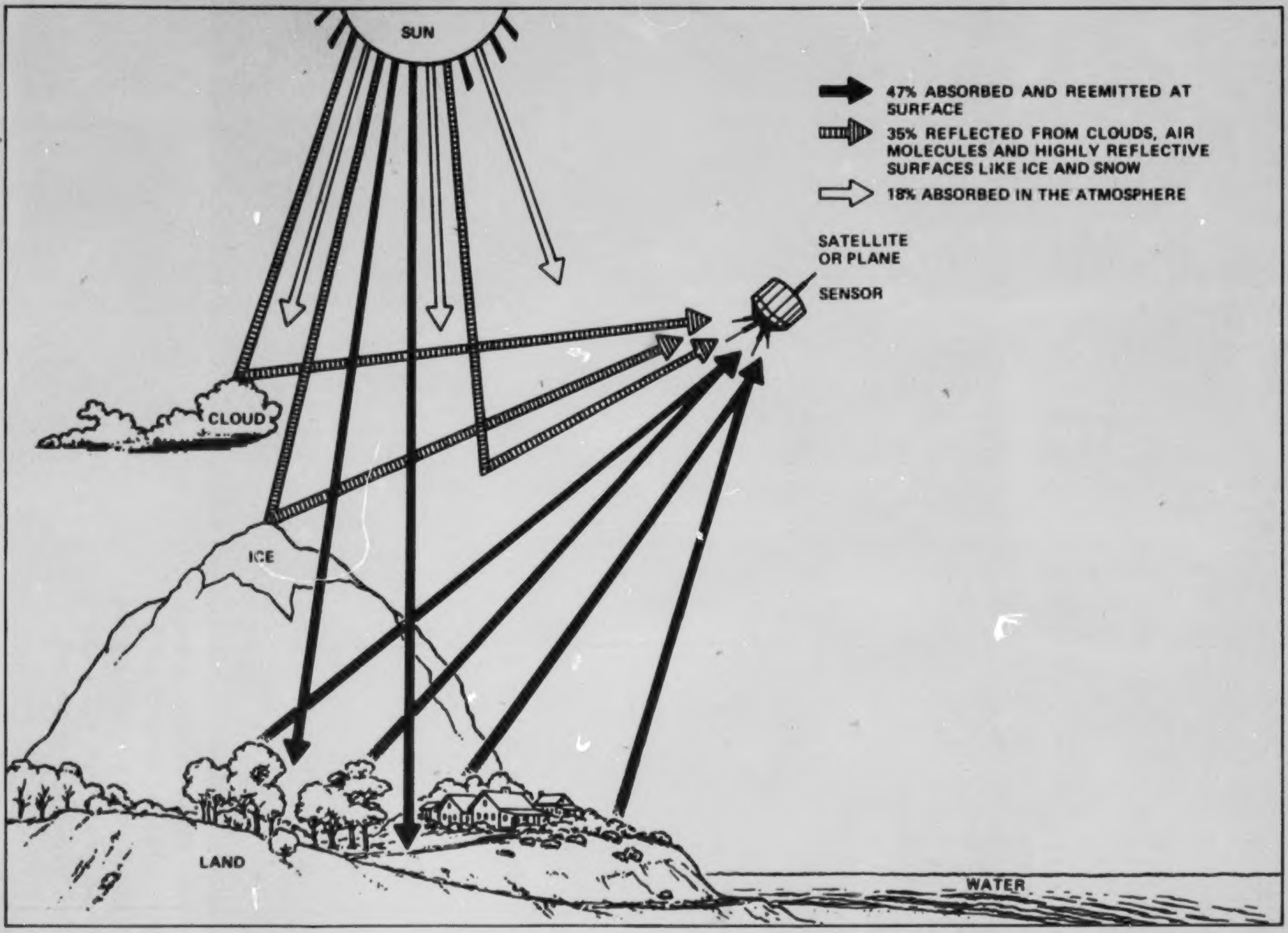

SUN
47% ABSORBED AND REEMITTED AT SURFACE
35% REFLECTED FROM CLOUDS, AIR MOLECULES AND HIGHLY REFLECTIVE SURFACES LIKE ICE AND SNOW
18% ABSORBED IN THE ATMOSPHERE
SATELLITE OR PLANE
SENSOR
CLOUD
ICE
LAND
WATER

Fig. 8 Solar Energy in the atmosphere.

infrared and thermal, the wispy cirrus clouds at high altitude are often semi-transparent. The density of the droplets, thickness of the layers, and extent of the cover are the major factors affecting light transmission. While microwave and, to a lesser extent, ultraviolet can penetrate cloud banks, these portions of the solar spectrum are relatively weak. Thus, clouds often hamper the transmission of solar radiation in the lower 20 km (12 mi) of the atmosphere.

Large particles, with radii from 1 to 20 micrometers, become important scattering agents in the last few kilometers of the atmosphere, especially near urban areas. Due to their size, these particles scatter almost uniformly at visible wavelengths, producing the bleak gray skies often seen over large cities. These airborne scatterers consist of soil and rock fragments, smoke and ash from forest fires, salt spray, volcanic debris, and chemical products of various natural and man-made substances. These include swamp gas (methane), ammonia, hydrocarbons, sulfur dioxide, and nitrogen oxides. Once formed, the particles also provide a nucleus for condensation in more humid climates, resulting in fog, smog, and clouds that further impede the passage of light.

Despite these barriers, considerable sunlight does reach the surface of the Earth, where it is absorbed by the soil, plant canopy, water, buildings, and other features which remote sensors examine. People recognize these objects in part by their color, which is determined by the combination of colors (wavelengths) in their various intensities which the objects reflect (i.e., fail to absorb). In remote sensing, the concept of color is extended to include the full spectral range of the sensor and the term "spectral signature" is applied to it. Thus, clear water will have a signature high in blue and green and low in red and infrared, while vegetation will exhibit its peak reflection in infrared and green. Since the human eye cannot detect infrared emissions, people describe water as blue and plants as green.

Although the radiation detected by remote sensors is shaped by the Sun, the atmosphere, and the reflecting surface, the last of these produces the greatest variation in color distribution and intensity. This difference in the reflection of electromagnetic radiation allows remote sensors to distinguish surface features and makes them useful in exploring and monitoring the Earth.

THE NATURE OF LIGHT

Vocabulary - Define the following terms in detail.

- Fusion
- Fission
- Light
- Electromagnetic Radiation
- Wavelength
- Wave Velocity
- Photons
- Fraunhofer Lines
- Micrometers
- Solar Radiation
- Sun Spots
- Electromagnetic Spectrum
- Molecules
- Ultraviolet Rays
- Spectral Signature
- Microwave Energy
- Radio Waves
- Gamma Rays
- Infrared Energy
- X-Ray Energy
- Blackbody

Questions - Answer the following inquiries in detail.

1. Explain the evolution of a star as it relates to magnitude, temperature, and color.
2. Define light.
3. Present a detailed discussion of the complete electromagnetic spectrum and emphasize the visible light portion.
4. How does the Earth's atmosphere produce the "greenhouse effect"?
5. What are Fraunhofer Lines?
6. What are the effects of the atmosphere on solar radiation?
7. Why do atmospheric molecules absorb sunlight only at certain wavelengths?
8. What is the effect of a cloudy day on sunlight?
9. Discuss scattering.
10. What is the relationship between remote sensing and reflection of the electromagnetic spectrum?

REMOTE SENSORS

This section briefly describes a variety of sensors which are used for remote sensing purposes. When used on various platforms (balloons, aircraft, helicopters, spacecraft, etc.), these sensors provide a full range and combination of capabilities which exist for collecting remotely sensed data. Platforms are discussed in the next section. In general, sensors fall into two primary categories: photographic and nonphotographic. While presented as two subjects, frequently these sensors are used in combination to produce the best results.

Photographic Systems

Cameras

Remote sensing history records several instances of cameras used on balloon platforms. In addition to earth bound use, hand held cameras have been pointed out the side openings of low-flying aircraft. Camera systems have become much more sophisticated since World War II. As a result a variety of systems are available for numerous earth resources applications. Common to aerial camera systems, including those used in manned spacecraft, are four basic components: a film magazine (to store film), a drive mechanism and shutter system (to advance and expose film), a lens or camera cone (to support the lens), and the lens itself (to focus light).

Five basic types of aerial and spacecraft photographic camera systems are presently in use: reconnaissance, mapping, panoramic, strip, and multispectral. No less than 100 different models within these five categories have been used. Variations on these basic types are always being developed to meet specialized needs.

Reconnaissance camera systems come in a variety of configurations and are the most important camera type used for earth resources remote sensing applications. Their purpose is to provide maximum image resolution with moderately good image positional accuracy. In other words, they produce a clear picture whose parts may not be in exact proportion to each other. This system is the work-horse of remote sensing and is used on many types of sensor platforms. A typical system is shown in Figure 9 mounted in the right interior of a low altitude aircraft. Also depicted is the photo-navigator and his equipment. Figure 10 is a photograph of Titusville, Florida, obtained using the camera system showing rural and urban development as well as other recognizable features.

Mapping camera systems, sometimes called cartographic or metric cameras, are relatively complex. These cameras are designed to produce maximum positional accuracy with reasonably good resolution (the opposite of the reconnaissance systems). As their name implies, these cameras are the tools of cartographers. They are routinely used to acquire photography for mapping purposes. Reference markers, flight information (day, time, and altitude), and camera data are usually recorded on each film frame for use after processing.

Panoramic cameras attempt to combine wide angular coverage and high resolution in a single system. The panoramic principle has been used by commercial photographers for many years to produce large group pictures. In this application the camera is rotated mechanically about its

Fig. 9 A typical reconnaissance camera system mounted in a low altitude aircraft.

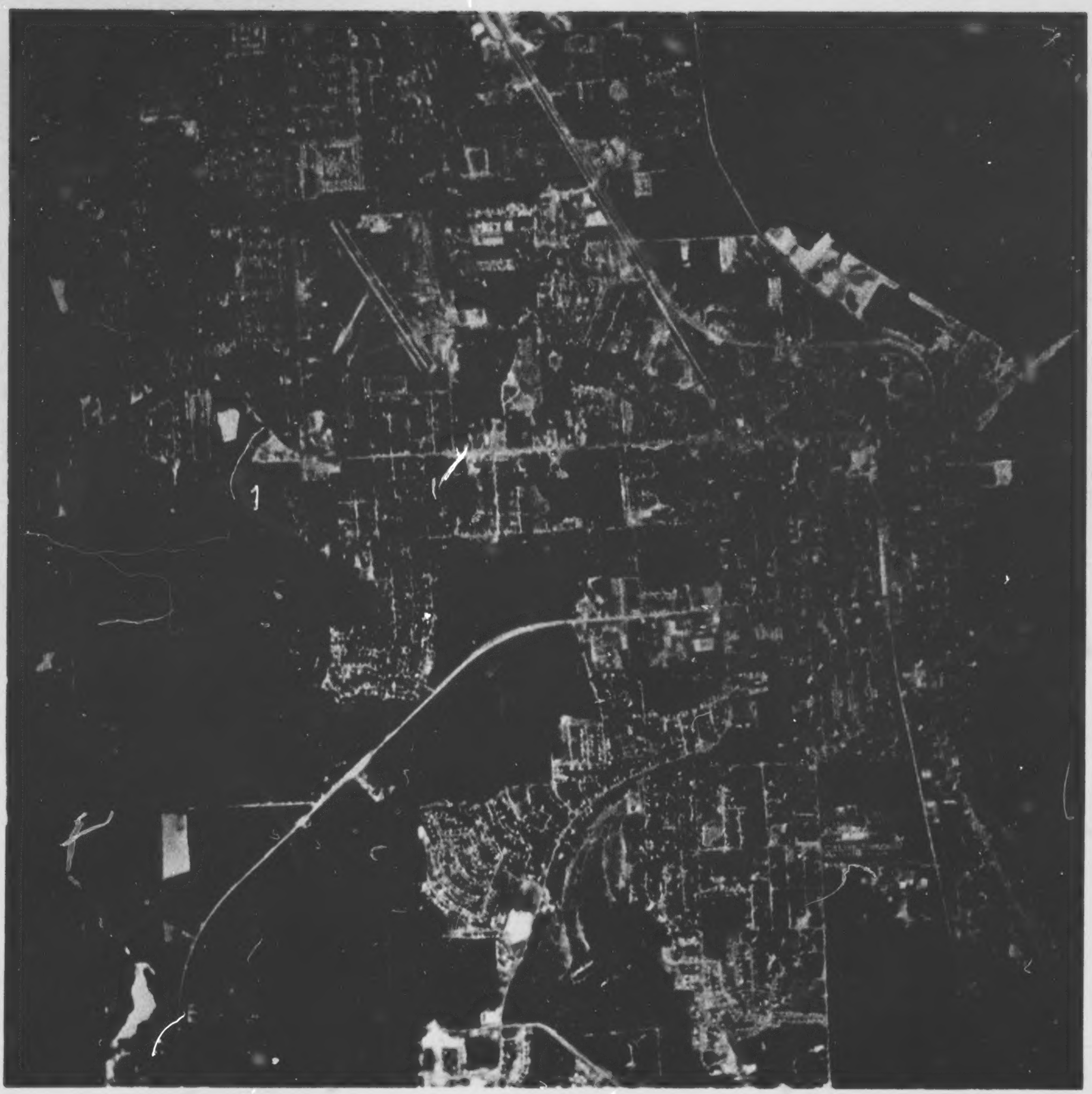


Fig. 10 A color infrared aerial photograph of Titusville, Florida.

vertical axis. The resulting long and narrow photograph is generally of good quality. From an airplane either a prism or the lens itself is rotated to provide coverage from horizon to horizon in a direction perpendicular to the flight path.

The strip camera, a relatively old system, was perfected during World War II. It was used to provide maximum information along a narrow strip by low flying aircraft. This camera works on the simple principle of moving film past a shutterless opening (a slit) at exactly the same speed as the image moves beneath the camera platform. While this is a useful system, the inherent problem is distortion along the flight line. This can be serious even though images are sharp and distinguishable. For this reason strip cameras are not widely used for earth resources purposes.

Multispectral cameras are usually reconnaissance systems--but that's where the similarity ends. There are two basic types. The first consists of a single camera body with multiple lenses as shown in Figure 11. Photographic data of the Walt Disney World Theme Park located southwest of Orlando, Florida, is shown in Figure 12. The other consists of a grouping or array of identical synchronized cameras (usually four or six) like that in Figure 13 shown mounted in a helicopter. Data obtained from this type of camera system is similar to that shown in Figure 12. In both configurations different film and/or filter combinations are possible over the full range of photographic coverage. In all situations, pictures are simultaneously obtained to provide imagery containing different spectral bands taken at the same instant. This allows great flexibility, which will be explained in more detail in the next section on films and filters.

Films

As is commonly realized, there are numerous types of film used for a wide variety of purposes. This is also true of aerial and spacecraft films. In general, aerial and spacecraft photography records light energy in the visible (blue, green, and red) and near infrared portion of the electromagnetic spectrum. This range lies between 0.4 and 0.8 micrometers (μm) as shown in Figure 14. For the purpose of this discussion, the only film types which are described are black-and-white, multispectral color, and infrared.

Black-and-white film is the least expensive and is simplest to use and process. In many instances standard black-and-white aerial film is sufficient to do the job required. This film is sensitive to wavelengths of approximately 0.36 to 0.72μm--which is essentially the range of the human eye. The subtle shades of gray as well as black-and-white allow our eyes to distinguish object and shape differences, thus providing information.

Multispectral color film is widely used in aerial photographic application. In spite of its higher cost, it is extremely useful because it records "real world" images in a familiar way. Color photography is invaluable for earth resources studies because of the large number of subtle color distinctions. Studies have shown that the human eye can separate more than 100 times more color combinations than gray scale variations (i.e., different combinations of black-and-white). The ratio is approximately 20,000 to 200. Although significant improvements since 1960 have made possible the color film of today, the basic principle remains the same. Multiple layers of emulsion on

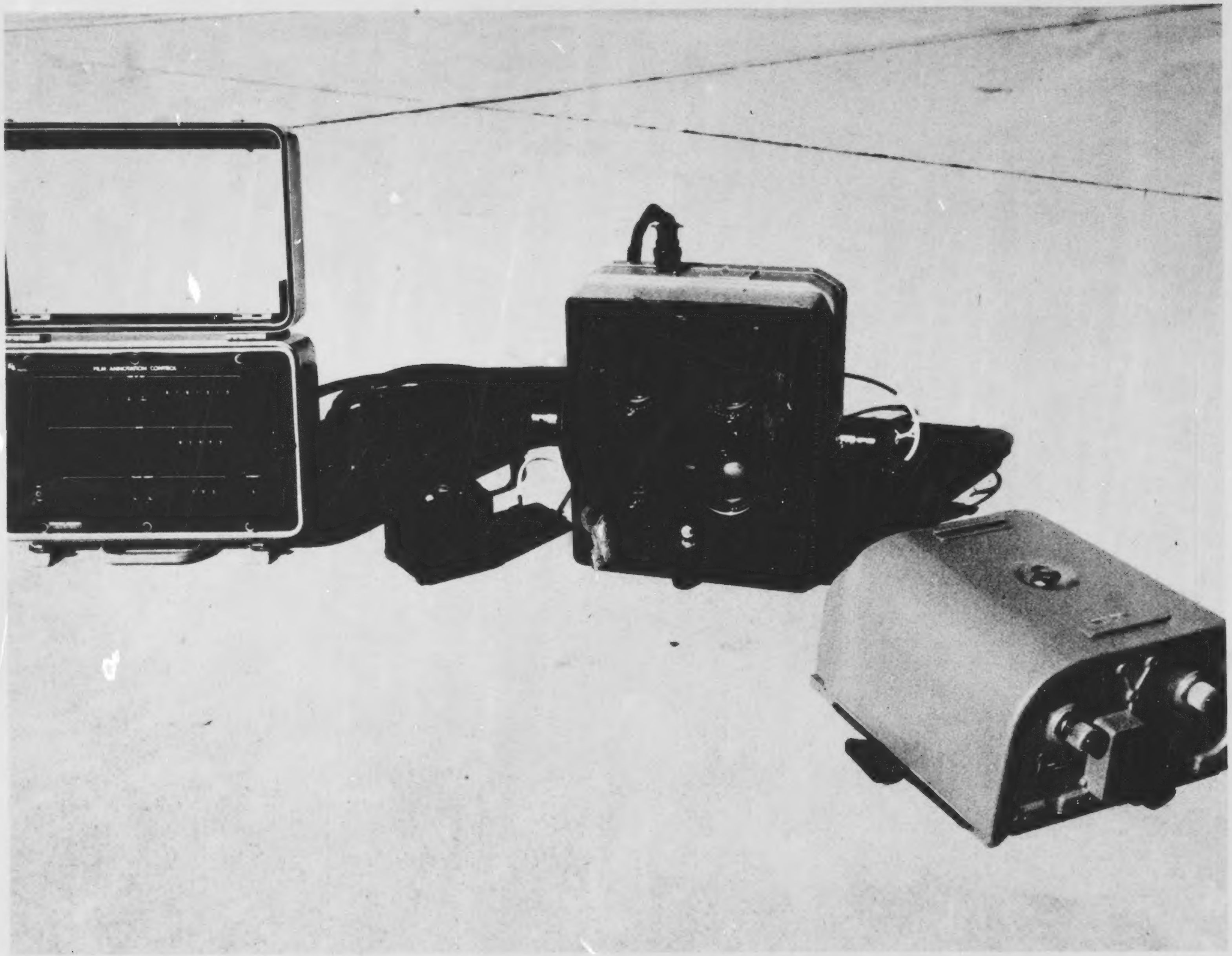

FILM ANNOTATION CONTROL

Fig. 11 A multispectral camera system with multiple lenses.

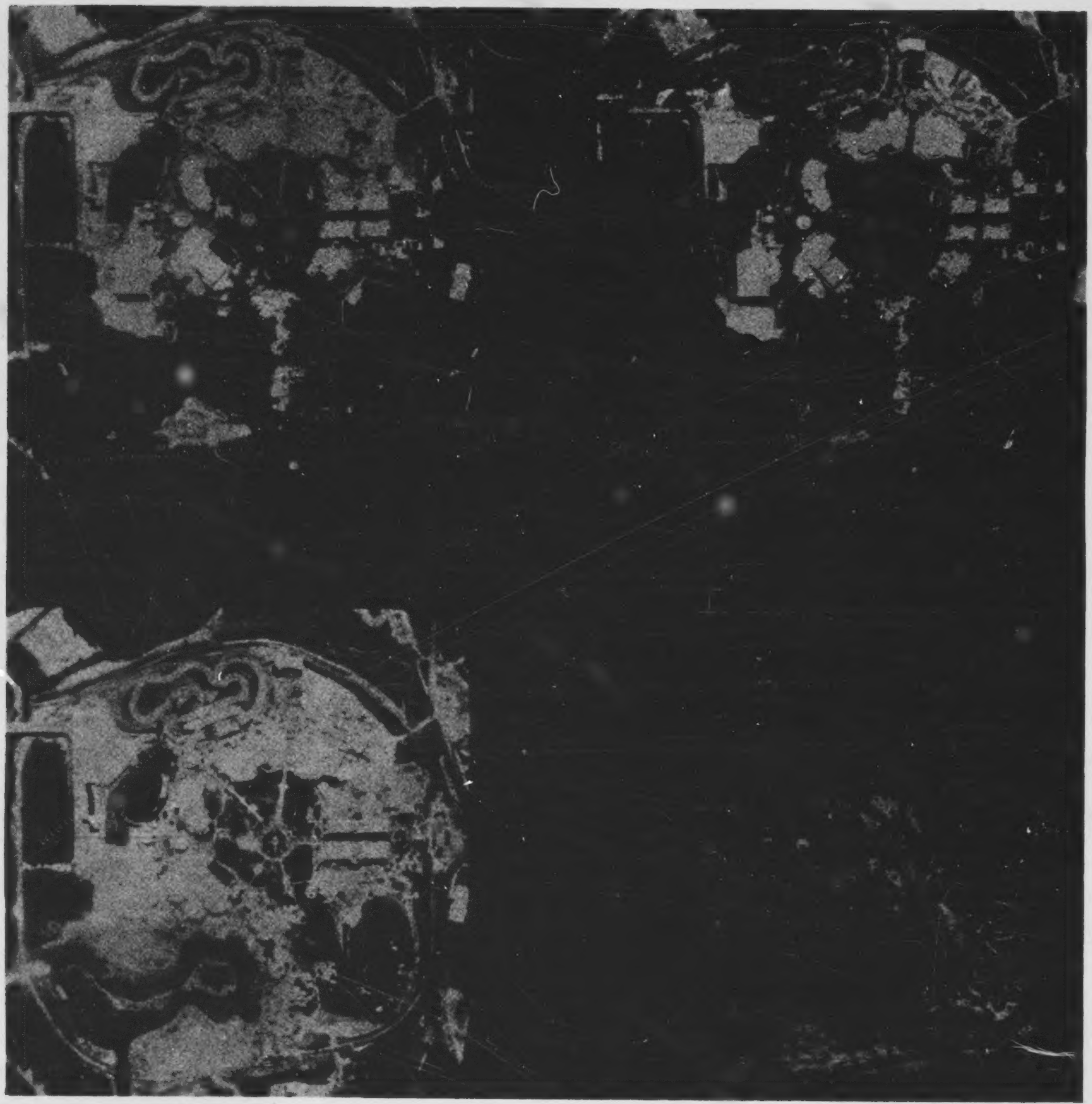


Fig. 12 Multispectral photographs of Walt Disney World taken with the camera system shown in Figure 11.

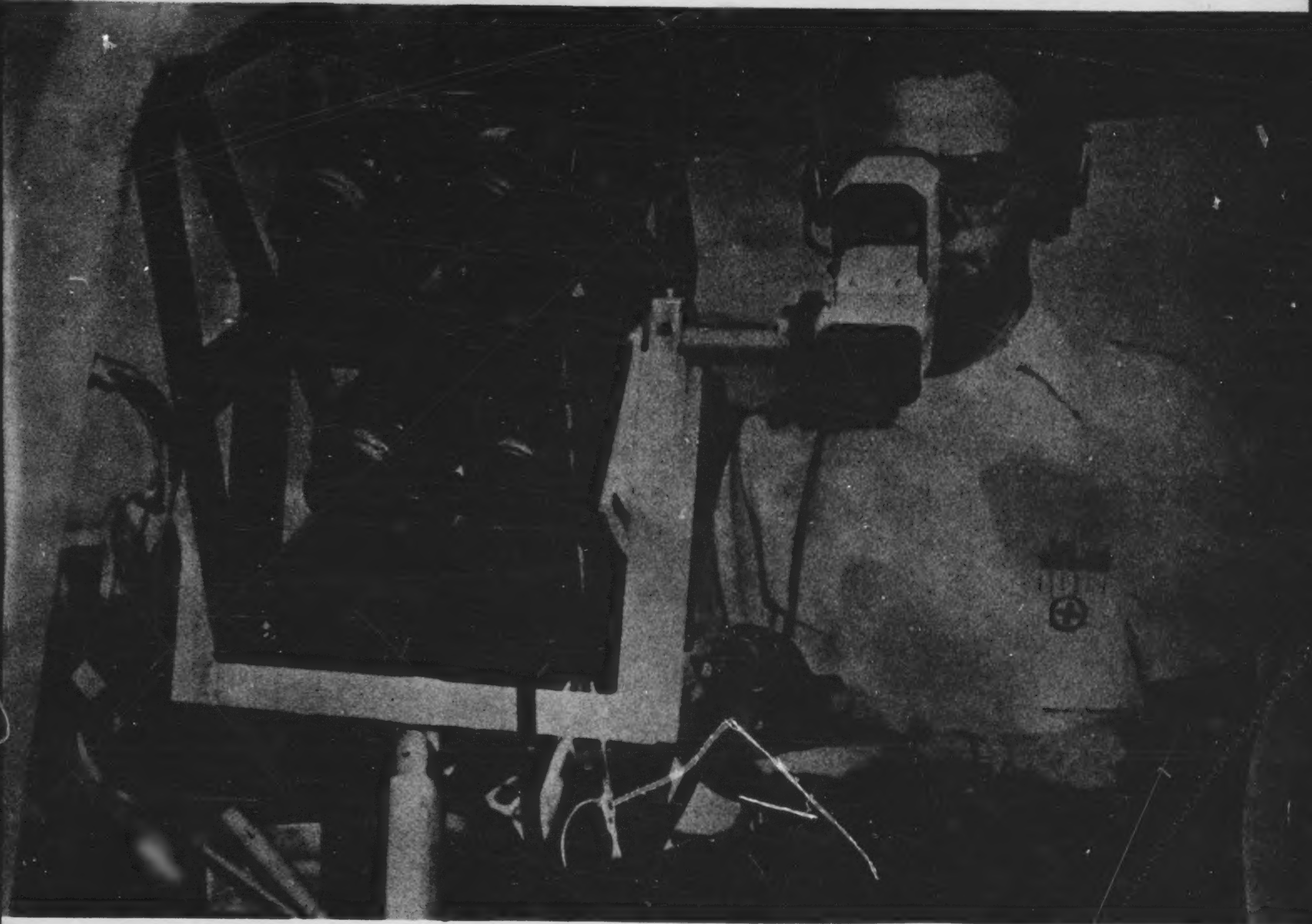


Fig. 13 A synchronized multispectral camera system mounted in a helicopter.

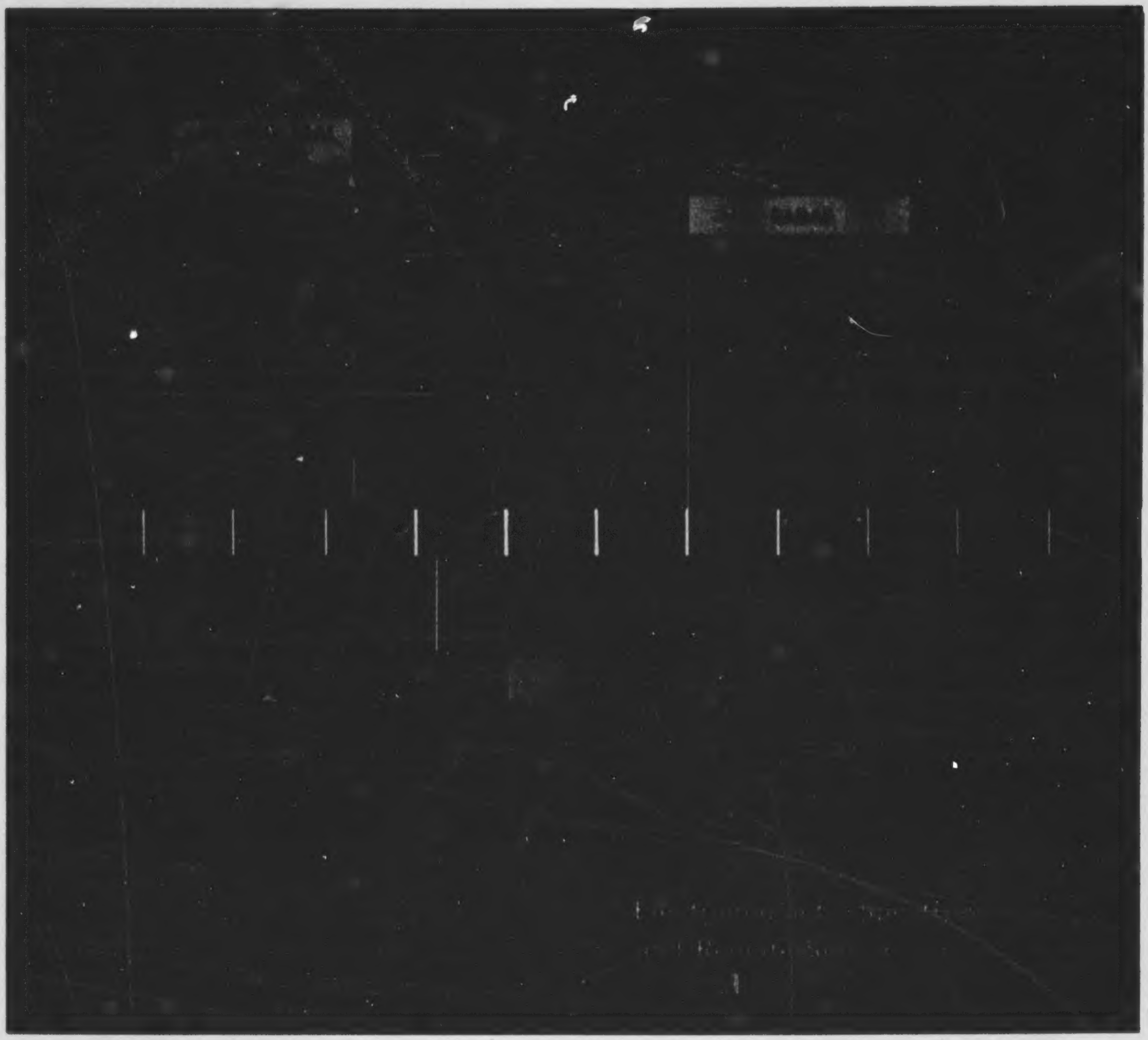


Fig. 14 Electromagnetic spectrum and remote sensors.

the film base use different dyes, each sensitive to a different range of wave lengths.

The use of infrared film for earth resources purposes has increased substantially. While infrared film may be black-and-white, color infrared includes three emulsion layers sensitive to green, red, and infrared to achieve its full color effect. This film has a spectral sensitivity which extends from approximately 0.36 to 0.9 µm. In fact, recent technology has increased dye sensitivity so that certain infrared films have a spectral response to about 1.2 µm. However, aerial infrared film is still restricted to a maximum response of 0.9 µm.

While infrared films are less sensitive to the green portion of the electromagnetic spectrum, their sensitivity extends beyond the red (0.7 µm) into the reflected portion of the near infrared (0.7 to 0.9 µm). Commercially available in either black-and-white or color, infrared film has certain advantages over other types. For example, this film provides superior haze penetration, shows clear delineation between water and land boundaries, and is useful in detecting distressed plants. It is, however, not as useful as more conventional film in penetrating shadows, and its use requires almost cloud-free skies.

Ultraviolet film used in conjunction with high resolution reconnaissance cameras is sensitive in the near ultraviolet-blue range of approximately 0.3 to 0.4 µm. Like other films it is primarily dependent upon reflected solar radiation for image formation. It is, therefore, limited to daytime use. A further limitation arises because camera lenses are somewhat opaque at wavelengths shorter than 0.36 µm. High quality quartz lenses must, therefore, be used. In spite of these limitations, ultraviolet film has been found useful in atmospheric studies and in oil spill detection on water surfaces.

Filters

A wide variety of filters are used in remote sensing camera systems for a number of reasons. Filters serve to select, amplify, or eliminate portions of the electromagnetic spectrum. Some filters reduce the degrading effects of atmospheric scattering in the ultraviolet and blue portion of the spectrum for both black-and-white and color film. Other filters improve the uniformity of photographic images on film, cut-off certain wavelength ranges, or transmit only between a certain range. Still others affect the color balance in color photography by absorbing in the red, blue, or green bands. The use of filters is essential to good remote sensing photography.

Nonphotographic Systems

Thermal Scanners

The thermal scanner is one of the most common nonphotographic sensors presently in use for earth resources studies. Figure 15 shows the basic elements of a thermal scanner system including sensors, power supplies, and other electrical/electronic components. The system senses thermal emissions beyond the near infrared (1.2 µm). Depicted in Figure 16 are photographic data obtained from a thermal scanner. The thermal discharge for a power plant (upper left) into Miami, Florida's Biscayne Bay is shown while the color key at the right indicates water temperatures in Faranheit degrees.

Because of atmospheric absorption by water, carbon dioxide, oxygen, and ozone, infrared sensing must be performed in

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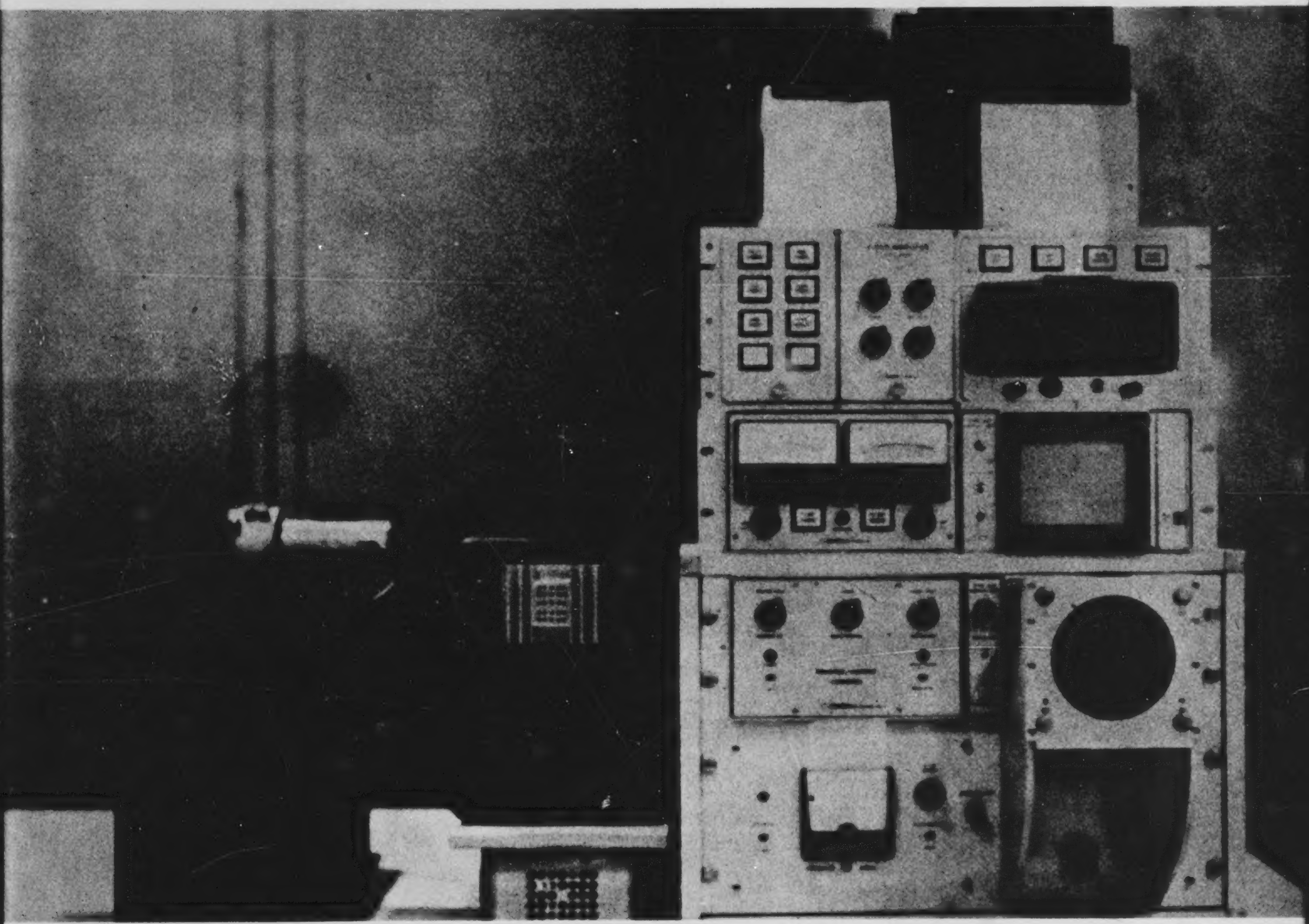

Fig. 15 A thermal scanner system.

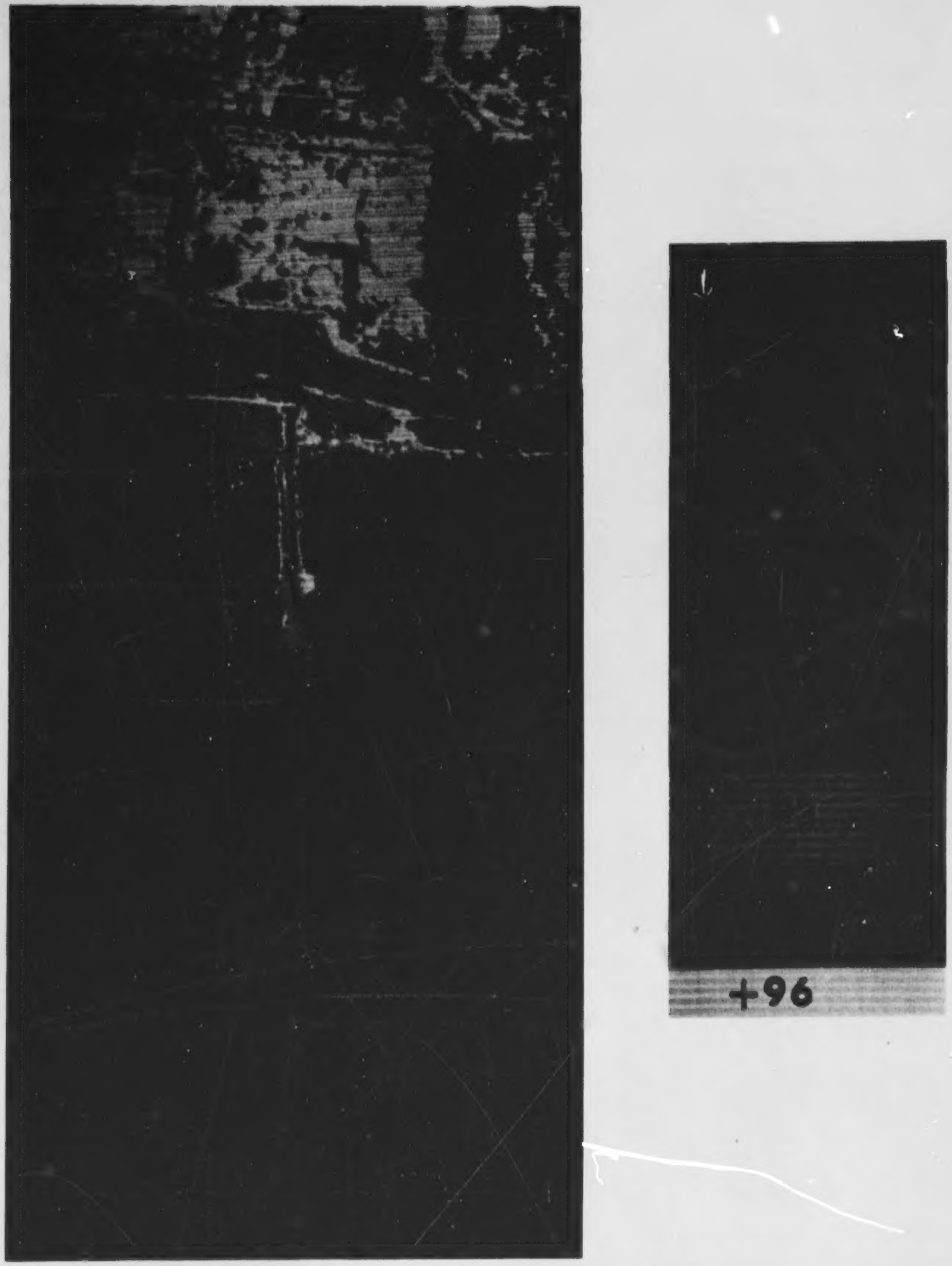

Fig. 16 A thermal scanner image of thermal discharge from a power plant.

wavelength ranges, sometimes called windows, where atmospheric effects are minimal. Those windows occur at 4.5 to 5.5 μm and 8.5 to 13.5 μm. Figure 14 indicates the range of surface radiation where thermal scanners are effective.

The basic principle used by these scanners is that emitted and reflected radiance from all surfaces on the Earth can be imaged. As discussed earlier, surface objects which absorb the Sun's radiant energy tend to increase in temperature and emit energy. They radiate primarily in the infrared parts of the electromagnetic spectrum. This radiant energy is imaged by temperature sensitive detectors. During daylight hours, it is estimated that there are approximately equal parts of reflected and emitted solar energy. At night, however, most of the observed energy is emitted. Thermal scanners have a distinct advantage over photographic systems in that they can operate in partial or total darkness.

Basically, a thermal scanner system is an electrical-optical-mechanical scanning device. It consists of a rotating mirror and a telescope that focuses radiation, through the use of a collecting mirror arrangement, on special detectors. These are extremely sensitive devices. They consist of electrical conductors coated with infrared sensitive materials such as mercury, copper, or gold-doped germanium and indium antimonide.

Because a thermal scanner's operating temperature would be similar to the ground temperatures it measures, the detectors must be maintained at extremely low temperatures. Nitrogen or helium in a liquid state is used to keep the detectors at temperatures of approximately -200°C (more than -300°F).

In operation on aircraft or spacecraft platforms, a precision mirror in the device scans the surface below and reflects an image of lines onto an electronic recording apparatus. These data are initially stored on magnetic tape and then processed at a later time.

Multispectral Scanners

As their name implies, multispectral scanners are used to record a scene below a remote sensing platform in a number of discrete sections of the spectrum called bands. While the operation of these systems is similar to that of the thermal scanner, data from as many as 24 bands (instead of only 1 or 2 on the thermal scanner) can be electronically recorded. These complex systems are calibrated using an elaborate set of precise standard sources for each detector before data are collected. The full multispectral range of these systems runs from ultraviolet to thermal infrared, including, of course, the visual range (see Figure 14). After data are recorded on magnetic tape, they are processed on the ground using specialized equipment.

Because the multispectral scanner system is a relatively new tool for earth resources investigations, its value is still being explored and documented. One obvious advantage is that data are simultaneously collected in discrete bands. These data can be added, subtracted, ratioed, and otherwise manipulated. They may also be analyzed separately depending on the ingenuity and needs of the user. Additional analysis techniques are continually being developed and are described in a later section on techniques and equipment.

Microwave Scanners

The microwave region of the electromagnetic spectrum includes wavelengths of approximately 0.1 mm to several meters. Because of the broad needs of earth resources activities, a portion of this region is important to investigations. Two types of microwave scanners are presently being used within a range of approximately 0.1 mm to 1 meter. These scanner systems are radar and the microwave radiometer. Their operating wavelength ranges are 1 cm to 3 meters and 100 um to 3 cm, respectively (see Figure 14).

Both systems scan a scene line-by-line to create an image. Since sunlight does not play a direct role in observations made by these instruments, they may be used day or night. Radar can also make observations through clouds. The primary distinction between radar and microwave radiometers is that radar is an active system and the microwave radiometer is passive; i.e., radar systems provide their own source of "illumination."

As has been discussed earlier, basic radar technology was developed during World War II as a means of detecting and locating various types of military targets. Recent radar advances and applications have made it a new and useful addition to the increasing number of earth resources sensors. Much work remains, however, in understanding its full potential.

Radar is classified as an active system and is unlike other sensor systems because of its inherent nature. In remote sensing, the area being scanned is "illuminated" by a burst of directed energy from an airborne transmitter. Differences among the elements of the landscape below struck by the directed energy cause variations in the return signals which are electronically recorded. These differences eventually appear as light and dark tones on photographic-like processed imagery. Figure 17 is an example of this type of data and shows the airport, houses, and other features in Melbourne, Florida.

Some radar antennas emit energy perpendicular to the platform's flight path and directed to the side, rather than looking ahead or in a circular pattern. This type of system is called sidelooking airborne radar (SLAR). It is the radar system most commonly used in earth resources studies. Strips of data collected by the airborne receiving antenna are electronically synchronized and joined to form continuous imagery.

A fairly recent advance in radar technology has created synthetic-aperture radars, which in effect allow the collection of high resolution data from relatively short airborne antenna systems. This method has the obvious advantage of eliminating the need for long and heavy antennas, which could not be carried by most platforms. Even more importantly, they permit high resolution independent of range--even at orbital altitudes. This remarkable advantage makes this system unique. All other sensor systems inherently lose resolution with distance from objects. In spite of this advantage, high power requirements have prevented satellites from being used as earth resources radar sensor platforms.

Microwave radiometers, the second type of microwave scanner, are passive systems. Unlike radar, they transmit no illuminating energy. These devices sense and measure radiant energy at selected wavelengths emanating from a scene. In fact, they record radiant temperature differences at or near the surface beyond the far infrared portions of the electromagnetic spectrum.

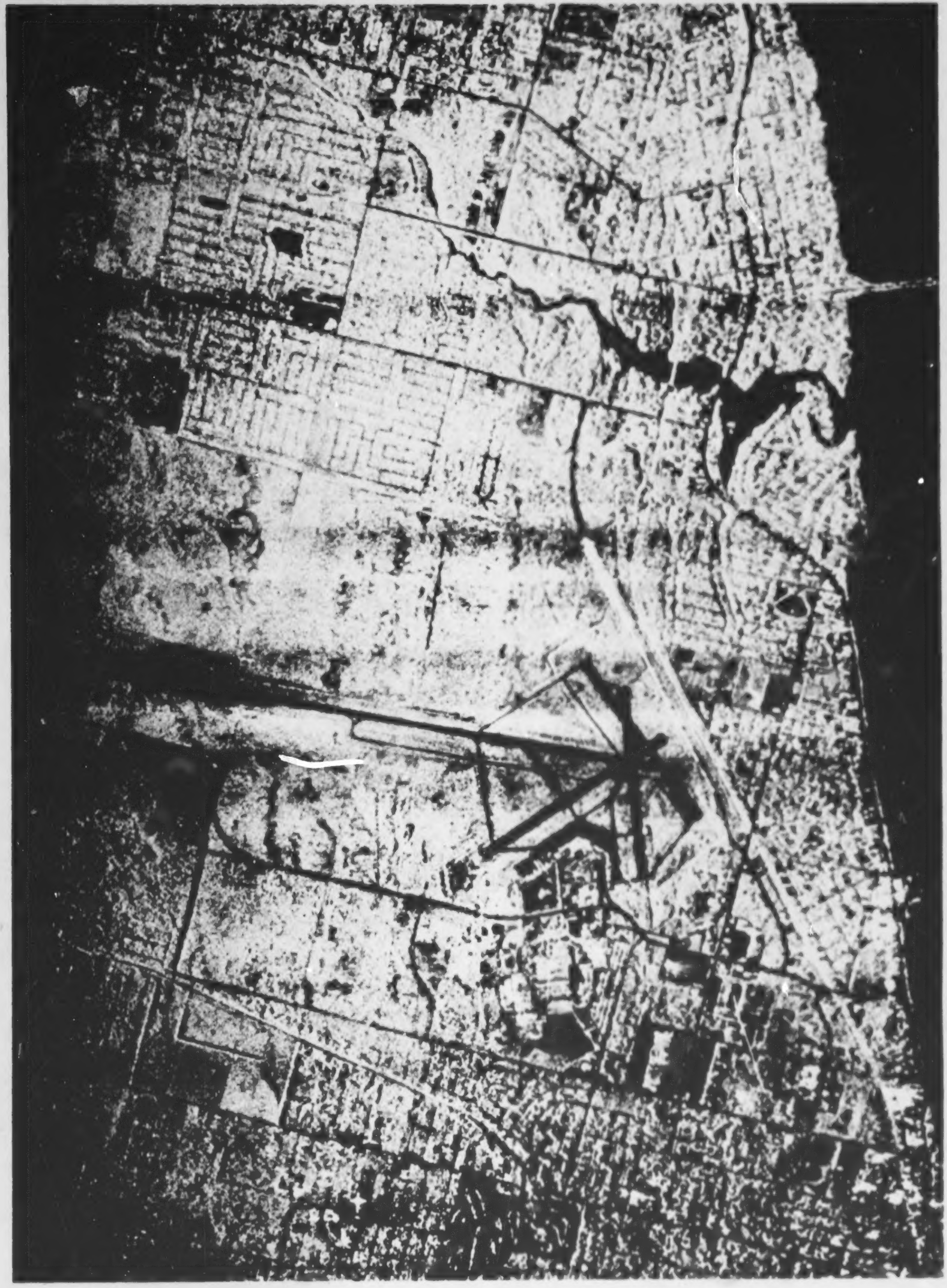

Fig. 17 A radar image of Melbourne, Florida.

Microwave radiometric sensing for earth resources purposes is also a relatively recent addition to remote sensing activities. This system has not found widespread use as a tool but its capability has not yet been fully exploited. Microwave radiometric technology was initially developed for the purpose of measuring emissions from extraterrestrial objects and from the Earth's atmosphere. More specifically, these systems have recently been used as an integral part of satellite remote sensors to study Venus, Mars, and the Earth remotely.

Television

Television camera systems have also been used for remote sensing purposes. Like photographic systems, they have served as sensors primarily in the visible range. Because the principles of television systems are generally known, discussion here is limited. It is important to recognize, however, that unlike photographic systems, television data can be transmitted to other locations quite easily because these data are electronic in nature. Television systems have not normally been useful in ranges much beyond the visible. A notable exception has been the use of three television cameras placed in LANDSAT satellites for earth resources sensing purposes. Each of these cameras views an identical square scene but in a different spectral band. These sensors are described in more detail later in the discussion of the LANDSAT platform.

REMOTE SENSORS

Vocabulary - Define the following terms in detail.

- Strip Camera
- Panoramic Camera
- Reconnaissance
- Mapping
- Multispectral Scanners
- Electromagnetic Spectrum
- Ultraviolet Film
- Filters
- Thermal Scanner
- Microwave Scanners
- SLAR
- Television

Questions - Answer the following inquiries in detail.

1. Explain the four basic components of an aerial camera system and their interrelated functions.
2. Discuss a reconnaissance camera system.
3. How are camera mapping systems utilized in environmental studies?
4. Explain the panoramic camera system.
5. Discuss the multispectral camera system.
6. Explain the electromagnetic spectrum.
7. Explain the different film types and their various applications.
8. Identify the basic elements of a thermal scanner system.
9. Discuss multispectral scanners.
10. How is microwave scanning used in data gathering?
11. Explain what a SLAR is.

Surface Observations

People have served as functional remote sensing platforms for centuries. Our eyes have surveyed and made visual observations and measurements of the Earth. But limited perspective, distance to be covered, weather conditions, difficult terrain, and sensor limitations and weaknesses have been our nemesis. To overcome several of these limitations, people increased their range by using animals and eventually mechanical vehicles. The four wheel -drive Jeep replaced the mule as the surveyor's means of covering larger areas. Boats of many descriptions have served well as both transportation systems and sensor platforms.

With the advancements of technology, scientists found methods of using fixed platforms, primarily in remote locations, to sense, record, and transmit data collected. With the development of satellites, small transmitters were used to relay remotely sensed data to more distant locations. The Data Collection Platform (DCP) system discussed later is an integral part of the LANDSAT Program and is a prime example of this technology and its application.

People working on the surface may never be totally eliminated because of the need to gather "ground truth". These surface measurements may be correlated with remote data to develop relationships, compared to predictions from higher altitude imagery to verify their accuracy, or may be simply used to supplement the data gathered from other platforms. While the extent of ground truth may be reduced, it will probably remain an important part of the remote sensing process.

Balloons

As mentioned in the evolution of remote sensing section, balloons were the earliest remote platforms used. Free flying balloons are still used when measurements to be obtained are relatively few and simple and when low cost operations are necessary. Flights to 50 km (165,000 ft) are possible. Sensor platform payloads of almost 5000 kg (11,000 lb) can be carried on lower altitude missions. Powered balloon platforms, although rarely used, have the advantage of being remotely controlled. To a limited extent they can be guided along a path or maintained over a desired area. A U.S. Air Force experiment during 1972 demonstrated the application of this type of platform.

Tethered balloons historically have been associated with wartime service and have been used to carry aloft various types of sensors. These payloads have included reconnaissance photographic systems and supportive equipment. Although generally restricted to wind conditions below 55 km/hr (30 knots), tethered balloons have been used in a number of research programs. Their primary use has been as support platforms for photographic systems used for archaeological studies. While limited in elevation and payload capability, these balloon systems have served to provide a broader and more synoptic view of larger areas than man could observe on the surface.

Aircraft

Another platform system more widely used involves aircraft of all types and capabilities.

Results of surveys using these systems have greatly aided scientists and conservationists in charting the features and resources of the Earth. While aircraft capabilities vary widely, they can be classified into three categories: low, medium, and high altitude.

A large number of low altitude--up to 9 km (29,500 ft)--aircraft are used for remote sensing applications. Figure 18 shows a typical low-altitude aircraft used for remote sensing purposes. These aircraft are also used by a number of commercial aerial mapping firms. Sensors used in these platforms can be pointed out an open window or door below 2 km (6,000 ft). Usually they are downward looking and are mounted inside or on the main fuselage or wings. Figure 19 shows the clarity of a low-altitude photograph of the Port Canaveral, Florida, inlet obtained at an altitude of approximately 2 km (5,500 ft). While low-altitude aircraft are relatively inexpensive to operate and maintain, they do suffer stability problems because of winds, thermal differences, and aircraft vibrations. Consequently, a general ground rule is that the higher the platform, the more stable it is.

Medium-altitude aircraft--9 to 15 km (29,500 - 49,000 ft)--provide a more stable and synoptic platform for sensor systems. A NASA remote sensor equipped Convair 440 is shown in Figure 20. If a broader perspective and smaller scale data are needed, a number of platforms are available. However, because of altitude requirements and high operational costs necessary for this type of aircraft, only limited commercial services are available. Modified military aircraft are normally used to obtain these data. Aircraft which fall into this altitude category are the Lockheed Electra, the Boeing 707, and the Convair 440. A medium-altitude photograph of Port Canaveral, Florida, and a portion of the Banana River is shown in Figure 21.

High-altitude aircraft--operating above 15 km (49,000 ft)--are very specialized platforms which have been developed for military reconnaissance purposes. However, with increased interest in earth resources studies, these aircraft have become available on a loan basis to NASA and other federal agencies for data collection purposes. Photographic, multispectral, thermal infrared, microwave, and radar sensors can be accommodated (frequently simultaneously) on these very sophisticated platforms. These high altitude systems with properly selected lenses and fields of view are also used to simulate satellite systems. Operating in the upper atmosphere, high quality, small scale data are possible.

An example of this type of aircraft is the X-15, a highly specialized rocket-powered experimental vehicle. The X-15 has been used to demonstrate photographic remote sensing from an altitude of more than 107 km (354,000ft). Aircraft originally developed as military systems, like the General Dynamics/Martin RB 57F, the McDonnell Douglas RF-4C, and the Lockheed U-2, have been modified and are now being used as data collection platforms by NASA.

Figure 22 shows a specially equipped high-altitude Lockheed U-2. Shown in Figure 23 is a U-2 photo of the Cape Canaveral-Merritt Island, Florida, area taken at 25 km (65,000 ft). The photo shows numerous land form patterns, sediment in water, and evidence of man's activities.

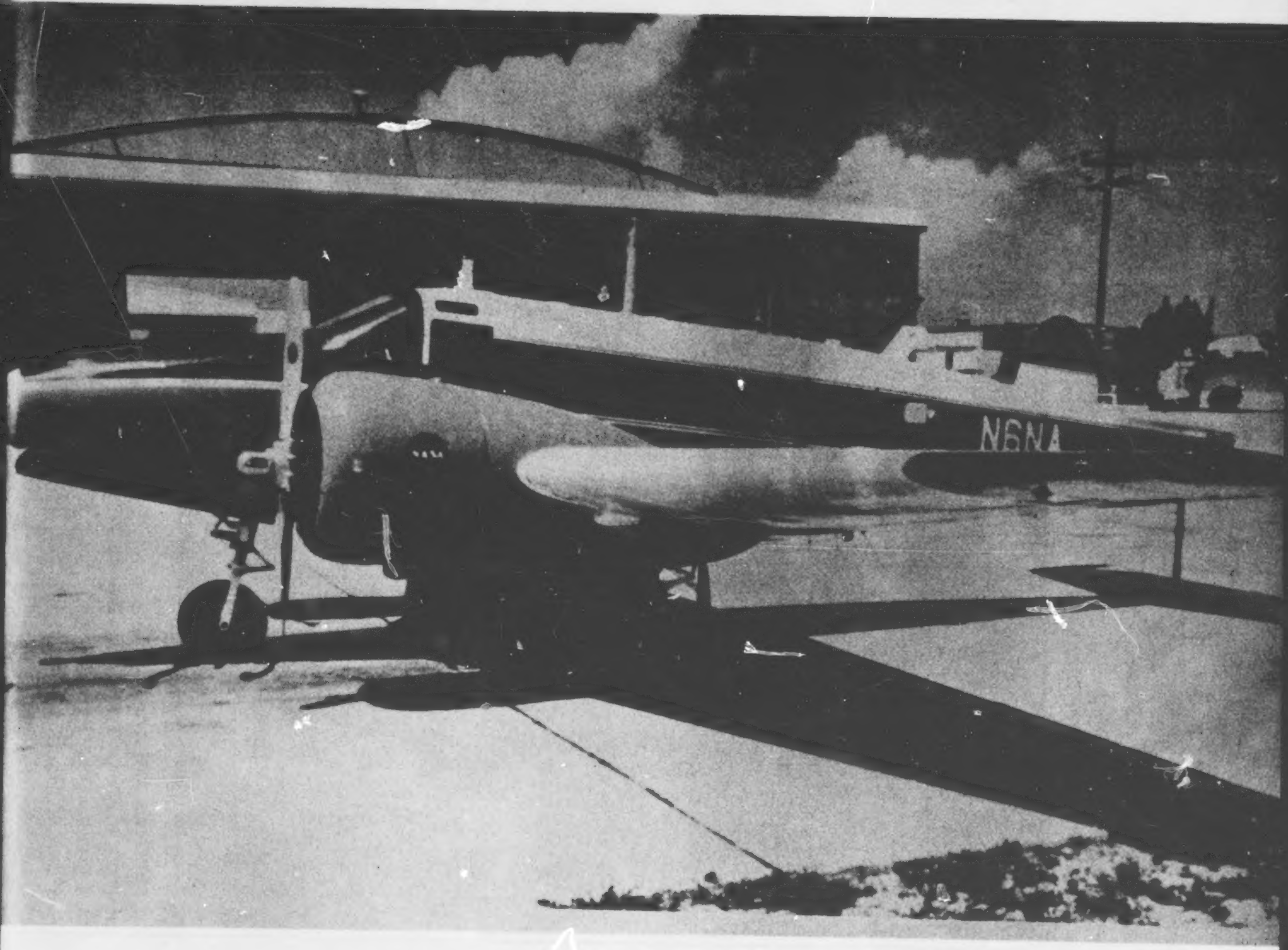

Fig. 18 A typical low-altitude aircraft.

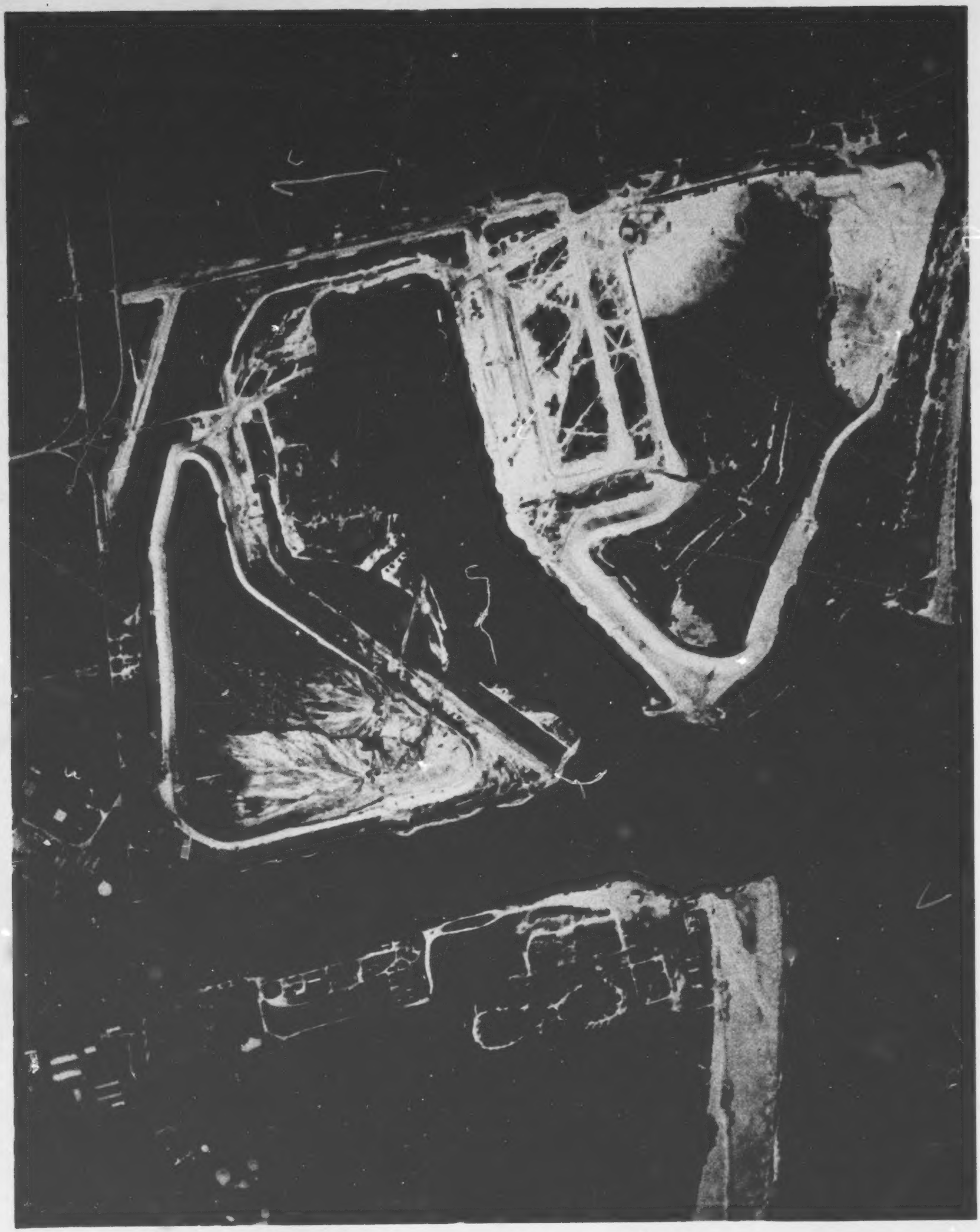

Fig. 19 A low-altitude color infrared aerial photograph of Port Canaveral, Florida.

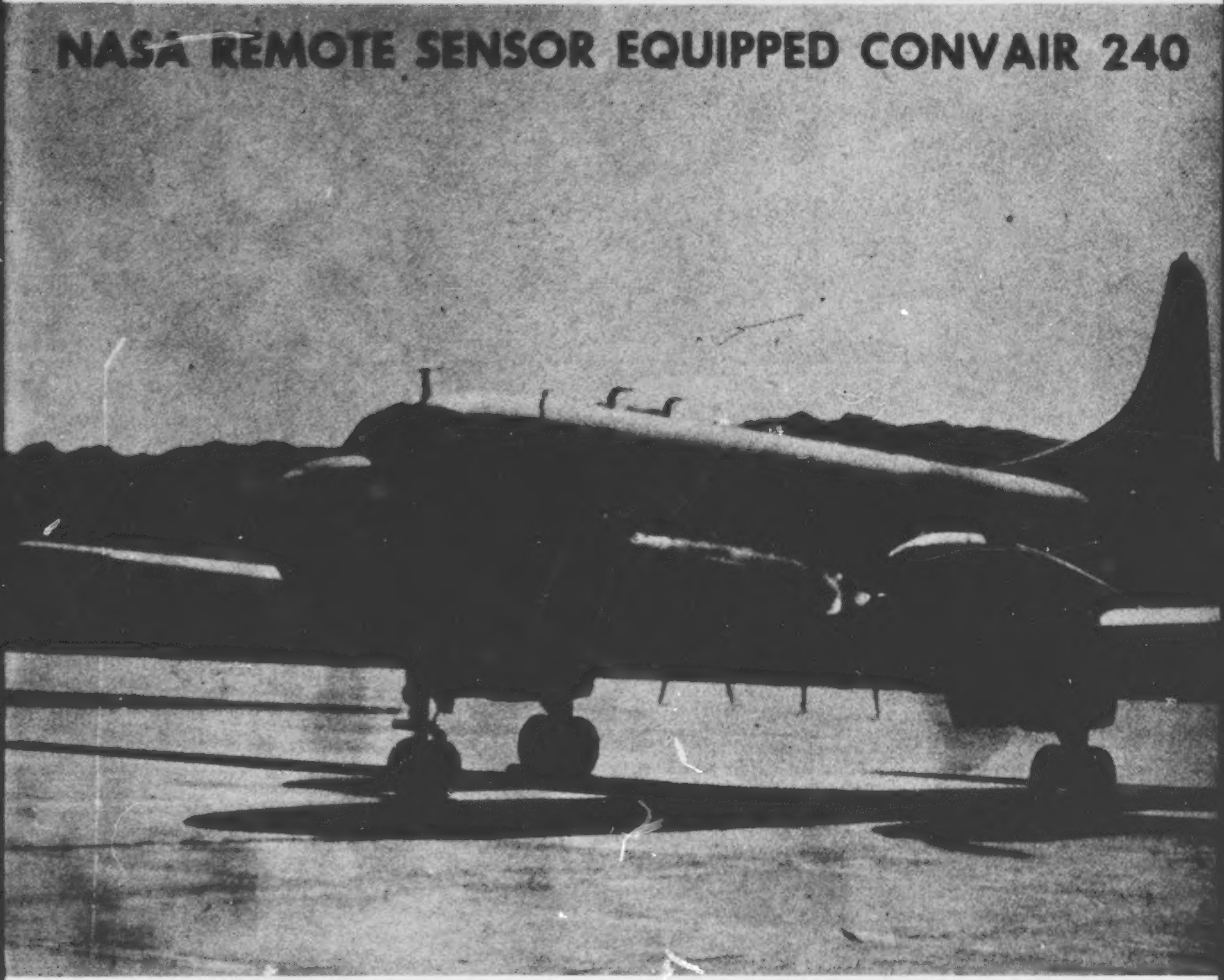
NASA REMOTE SENSOR EQUIPPED CONVAIR 240

Fig. 20 A typical medium-altitude aircraft.

Fig. 21 A medium-altitude color infrared aerial photograph of Port Canaveral, Florida.

Fig. 22 A high-altitude Lockheed U-2 specially equipped for remote sensing.

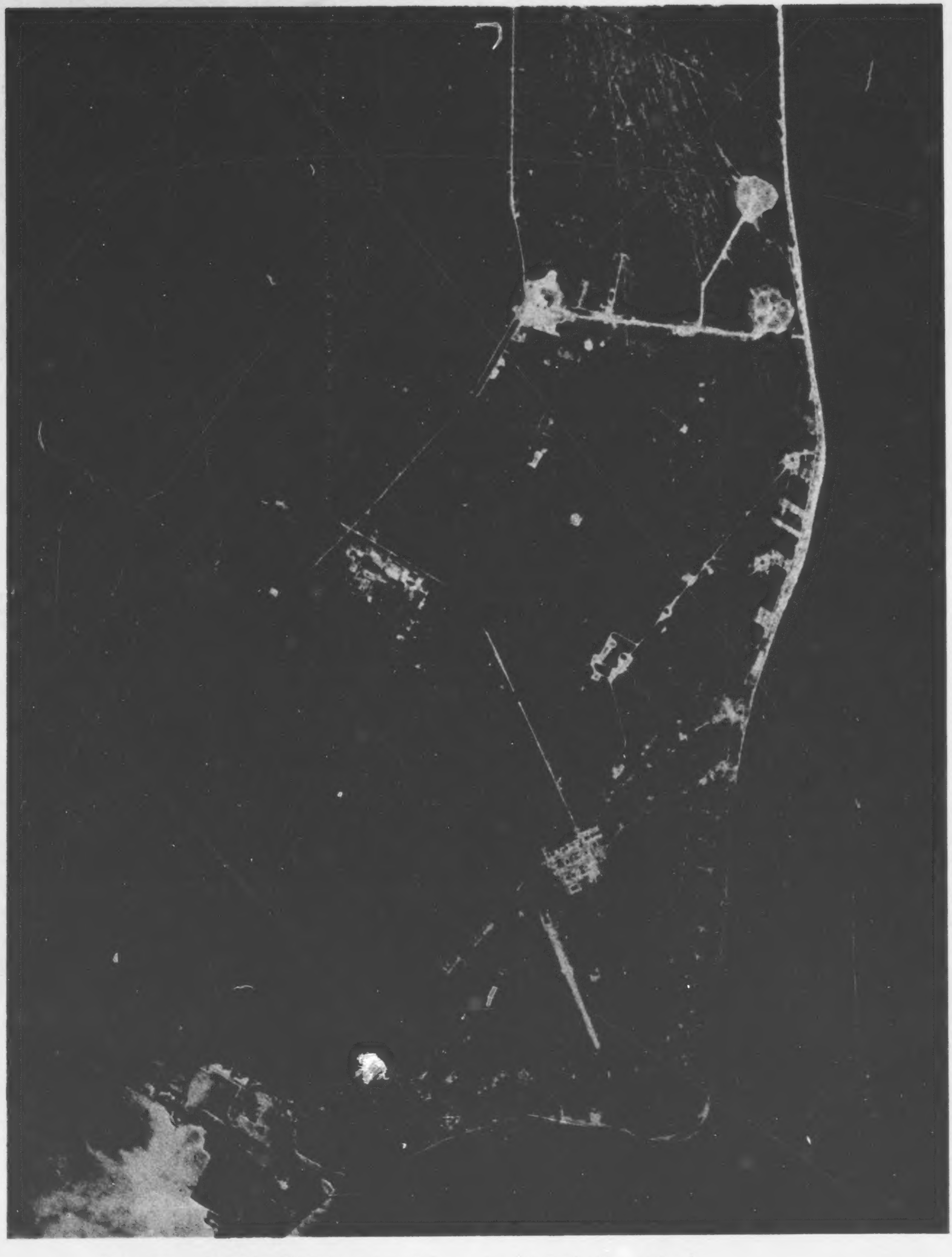

Fig. 23 A high-altitude color infrared aerial photograph of Cape Canaveral and Merritt Island, Florida.

Unconventional Aircraft

A number of unconventional aircraft platforms have been used on various occasions. These systems include helicopters, drones, dirigibles, and sailplanes. Each of these systems has capabilities that satisfy only certain limited applications. For example, helicopters have been used by the U. S. Department of Agriculture's Forestry Service to carry thermal infrared scanners for forest fire detection. Drones allow remote control operations but have not been used extensively for civilian applications to date.

Dirigibles, notably those owned by the Goodyear Tire and Rubber Company, are examples of lighter-than-air craft operating in the United States today. They have been used primarily as television and aerial photographic platforms for special events. Manned sailplanes are unconventional aircraft which have not been used to any great extent because of range and controllability limitations.

Spacecraft

For many applications the previously identified platforms, including man on foot, have sufficed. The Space Age has provided a new method and perspective for viewing the Earth and sensing its resources. Now very broad coverage of our entire planet is feasible. The age-old problems of being unable to view a sizeable portion of the Earth in one scene or on a frequent basis have been overcome by modern satellites. This perspective is now recognized as important in studying our global problems.

Spacecraft technology has provided an effective and economical way of overcoming stability, field of view, and recurring data requirements. These systems can be broadly classified as either unmanned or manned.

Unmanned Systems

While there are numerous unmanned Earth viewing systems, notably weather satellites, of primary importance to earth resources remote sensing is the LANDSAT system. LANDSAT-1 was originally called Earth Resources Technology Satellite-1 (ERTS-1) but was renamed on January 13, 1975. Often LANDSAT and ERTS are used interchangeably. Since the launch of the first LANDSAT on July 23, 1972, a second satellite was launched on January 22, 1975. Launches of even more sophisticated systems are planned.

Since mid-1972, LANDSAT satellites have provided vast quantities of data which hold the promise of greatly expanding our knowledge of our Earth and its resources. The LANDSAT system with its ground stations has been designed as a prototype system to gather and transmit large quantities of electronic imagery of great practical value. Much has already been learned by data users about urban development, farming and forestry, oceans and rivers, and other aspects of our environment. This has been done on both a repetitive and a long term basis.

LANDSAT satellites are butterfly shaped observatories (see Figure 24) orbiting the Earth at an altitude of 910 km (545 mi). The satellites circle the planet once every 103 minutes or approximately 14 times per day. Each daytime orbital pass is from north to south so that, except for part of the polar regions, the entire globe is repetitively overflown every 18 days. The sun-synchronous, nearly polar orbit was specifically selected for favorable sun angle. The satellite crosses the equator and all other points at approximately

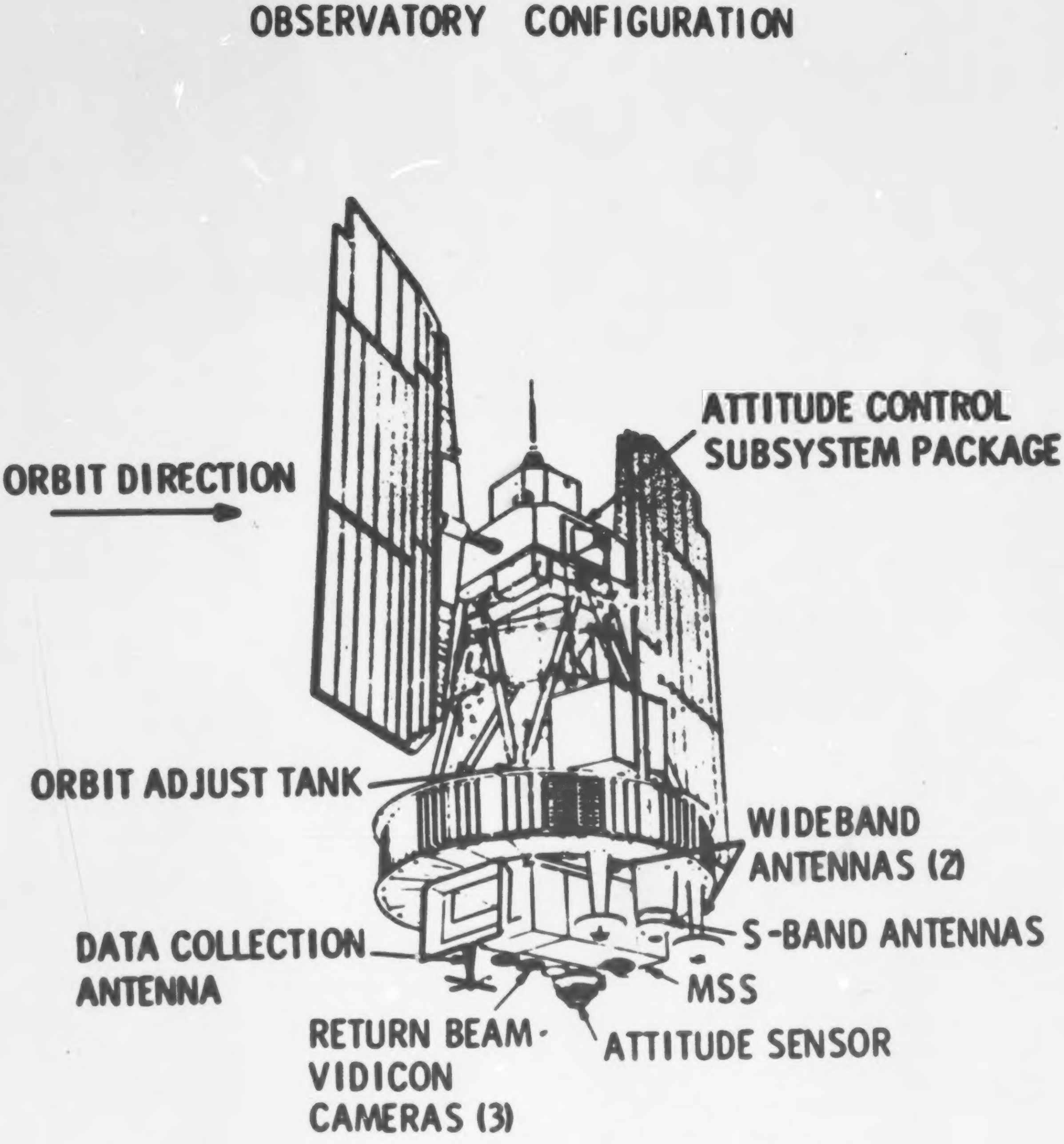
OBSERVATORY CONFIGURATION
ORBIT DIRECTION
ATTITUDE CONTROL SUBSYSTEM PACKAGE
ORBIT ADJUST TANK
WIDEBAND ANTENNAS (2)
S-BAND ANTENNAS
DATA COLLECTION ANTENNA
MSS
RETURN BEAM VIDICON CAMERAS (3)
ATTITUDE SENSOR

Fig. 24 LANDSAT

the same local time (mid-morning).

As Figure 24 indicates, in addition to an attitude sensor, an attitude control subsystem package, an orbit adjust tank, and antenna systems, three resources systems are included. They are: a Multispectral Scanner System (MSS), three Return Beam Vidicon (RBV) cameras, and [illegible] Data Collection System (DCS).

The MSS is an electro-mechanical line-scanning device which uses an oscillating mirror to scan the terrain passing beneath the spacecraft. Radiance from the Earth is collected by the mirror and passed through an optical system. It is then carried by fiber optics to a set of photomultiplier tubes. The scanner produces four synchronous images, each in a different band. The wavelength ranges of each band are:

Band 4 (green)	0.5 to 0.6 micrometers
Band 5 (lower red)	0.6 to 0.7 micrometers
Band 6 (upper red-lower infrared)	0.7 to 0.8 micrometers
Band 7 (near infrared)	0.8 to 1.1 micrometers

Band 4 is helpful in discriminating qualitatively the depth and/or turbidity of standing bodies of water. Band 5 is best for showing such topographic and cultural feature as drainage patterns, roads, and cities. Band 6 shows the best tonal contrasts for various land use practices and gives good land-water contrast. Band 7 is the best for land-water discrimination.

The RBV system consists of three television-like cameras mounted side-by-side and aligned to simultaneously image the Earth beneath the spacecraft. The cameras view the same area in three different spectral bands. The wavelength ranges in each band are:

Band 1 (blue-green)	0.475 to 0.575 micrometers
Band 2 (red)	0.580 to 0.680 micrometers
Band 3 (near infrared)	0.690 to 0.830 micrometers

These cameras do not contain film; their images are stored temporarily on photosensitive surfaces within each vidicon camera. These surfaces in turn are scanned by an internal electron beam to produce a video picture. This process requires 11 seconds to read out and transmit all three pictures. Because of functional problems, the RBV sensors on LANDSAT-1 had to be shut down on August 15, 1972. Although the LANDSAT-2 RBV system is operational, most of the data are still obtained from the MSS. RBV and MSS images cover approximately 185 x 185 km (115 mi) and overlap by about 10 percent along the satellite's path in temperate latitudes. Figure 25 is typical of the type of imagery obtained by the MSS. The area covered is Central and East-central Florida.

MSS and RBV data are transmitted to three data acquisition stations in the United States: one at NASA's Goddard Space Flight Center, Greenbelt, Maryland; another at Fairbanks, Alaska; and the third at Mojave, California. These station locations limit real-time coverage by the satellite's sensors to North America. It is possible to obtain data from other parts of the world in two ways. Two onboard wide band tape recorders are used to store data from areas outside the range of North American ground stations for later playback. In addition, several nations, including

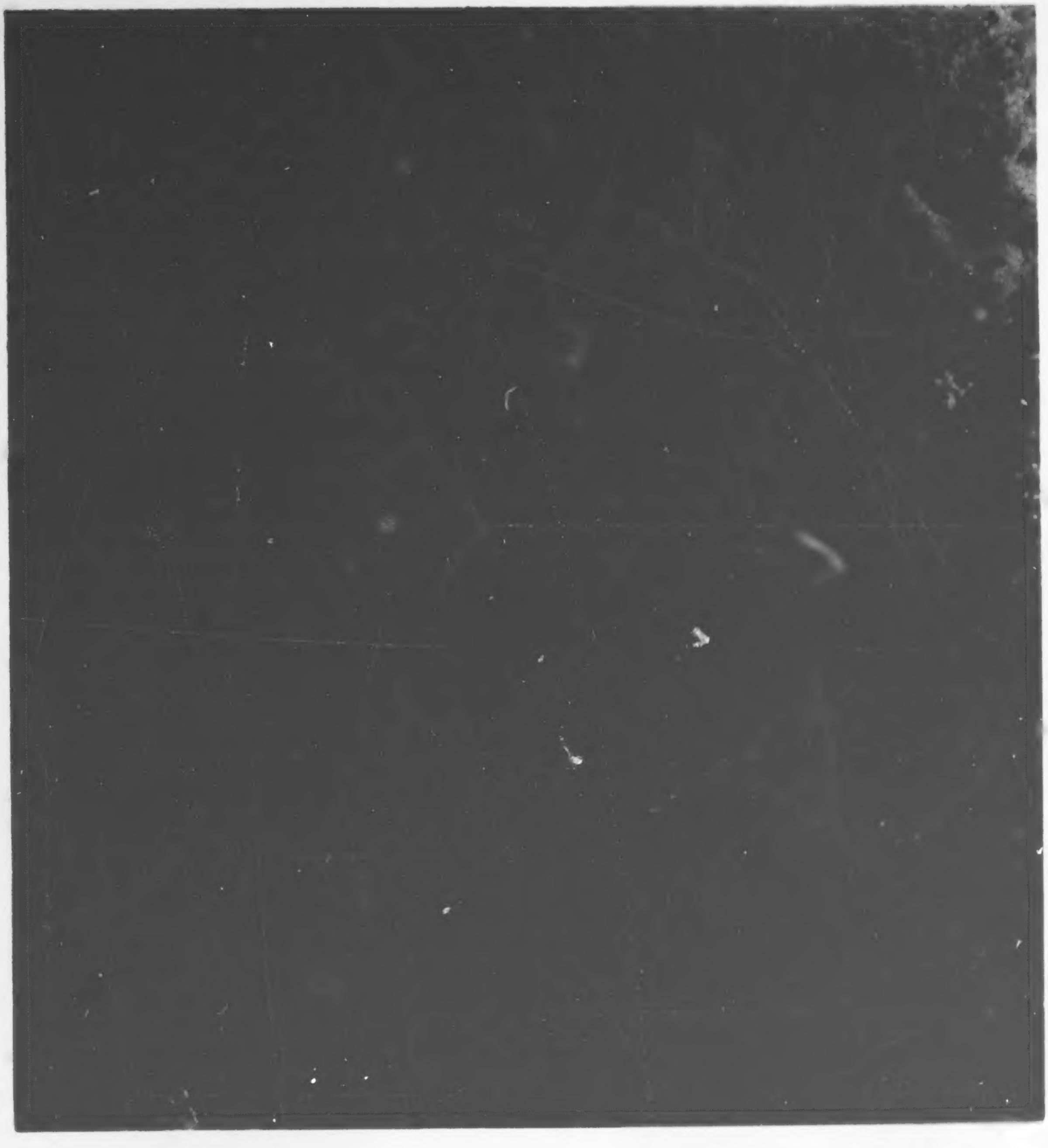

Fig. 25 A LANDSAT image of Central and East-central Florida.

Canada, Brazil, Japan, and Italy, have built their own LANDSAT data acquisition stations.

The Data Collection System (DCS) aboard the satellites obtain data from some 150 remote unattended, instrumented ground platforms located within the United States and its coastal regions. These data are relayed to the three United States data acquisition stations via telemetry links for delivery to users. Instrumentation on the remote platforms is capable of sensing local environmental conditions, such as water depth, current flow rates, soil moisture, snow depth, temperature, and humidity (see Figure 26).

In the future, more sophisticated LANDSAT and operational earth resources satellite systems and sensors will provide better data for a multitude of user needs. Sensors of higher resolution and thermal infrared band sensing capability will greatly increase user applications.

Manned Systems

With the advent of manned U.S. space programs, our perspectives on the solar system and our Earth have expanded greatly. Man has moved his personal experiences and perspective to a much higher elevation and has become a more integral part of the sensor platform system. Real time variation and correction of field of view and targets of opportunity have become possible.

Early U.S. manned space programs, like Mercury and Gemini, provided astronauts with a personal look at their planet through optical, electronic, and photographic means. During several Gemini flights, American astronauts directly viewed and photographed the Earth from outside their capsules. The more sophisticated Apollo spacecrafts have also served as earth resources data gathering platforms.

Of real significance to earth resources sensing activities was the NASA Skylab Program. Its objectives emphasized medical, solar, technology applications, and earth resources investigations. The program's main mission element consisted of a Skylab space station in a 435 km (270 mi) Earth orbit. Three different crews of astronauts composed of three members each lived and worked in the facility beginning in May 1973 for 28 days and 49 minutes; July 1973 for 59 days, 11 hours, and 9 minutes; and November 1973 for 84 days, 1 hour, and 16 minutes.

Skylab's Earth Resources Experiment Package (EREP) served as the most sophisticated sensor system ever placed into orbit. It contained a multispectral photographic facility (camera system) (S190A), an earth terrain camera (S190B), an infrared spectrometer (S191), a multispectral scanner (S192), a microwave radiometer/ scatterometer and altimeter (S193), and an L-band radiometer (S194) (see Figure 27. An example of photography obtained using the earth terrain camera (S190B) is included as Figure 28. Shown are the coral reefs and surrounding clear water of the Berry Islands--a string of islands in the Bahamian chain.

Data were acquired using EREP sensors during numerous orbital passes distributed among the three periods of manned Skylab operations. These data (photo-

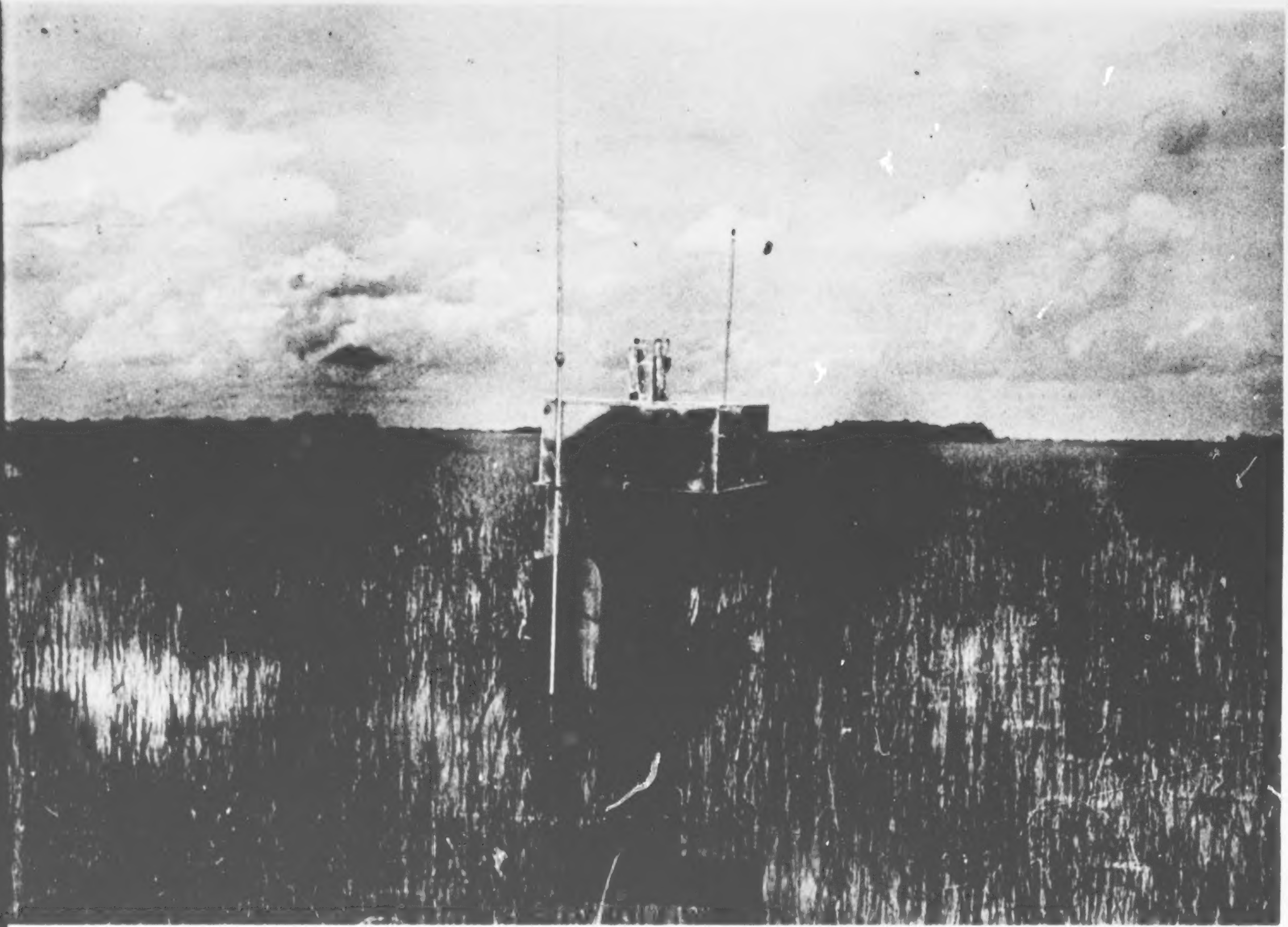

Fig. 26 A data collection platform.

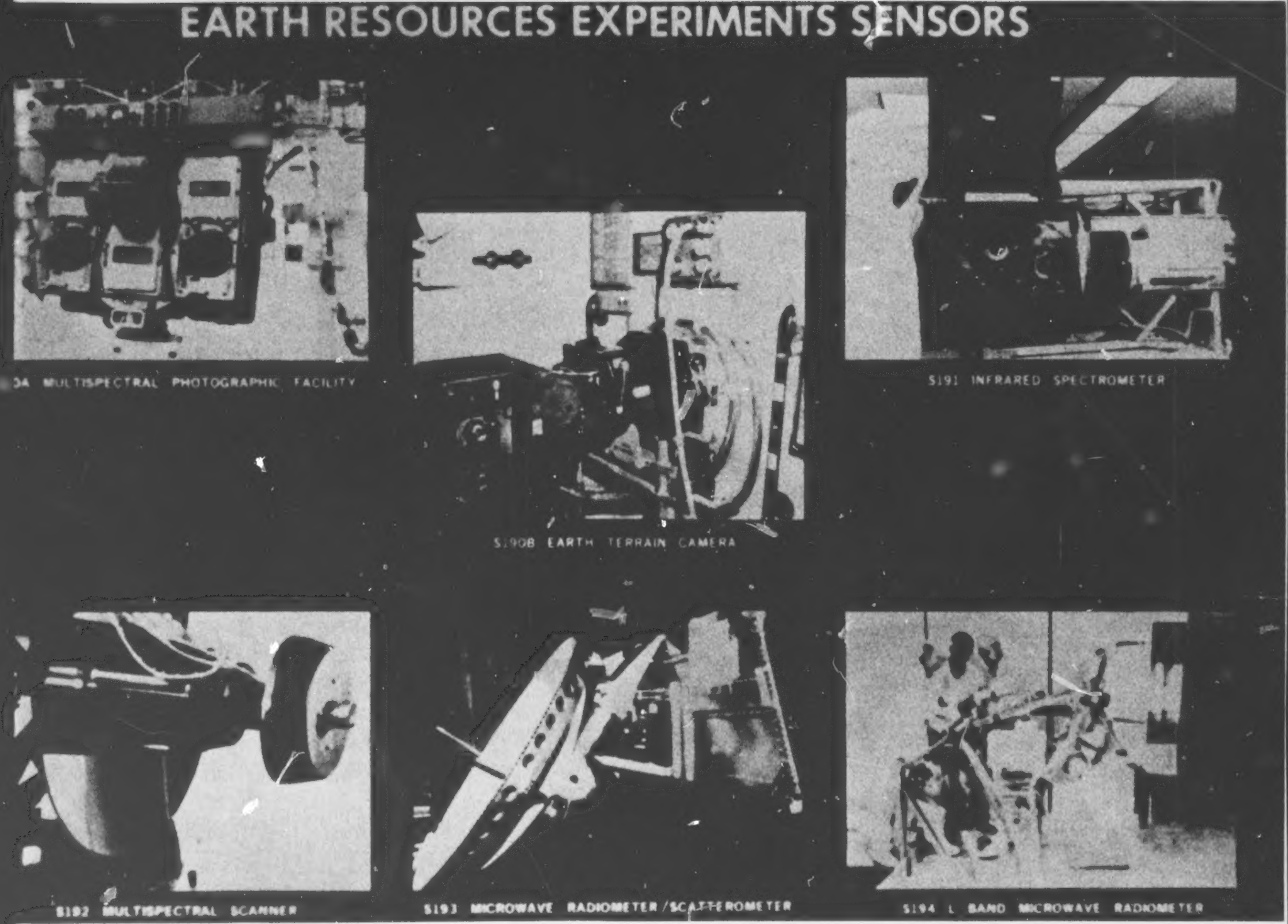
EARTH RESOURCES EXPERIMENTS SENSORS
0A MULTISPECTRAL PHOTOGRAPHIC FACILITY
S190B EARTH TERRAIN CAMERA
S191 INFRARED SPECTROMETER
S192 MULTISPECTRAL SCANNER
S193 MICROWAVE RADIOMETER/SCATTEROMETER
S194 L BAND MICROWAVE RADIOMETER

Fig. 27 Earth resources experiments sensors aboard Skylab.

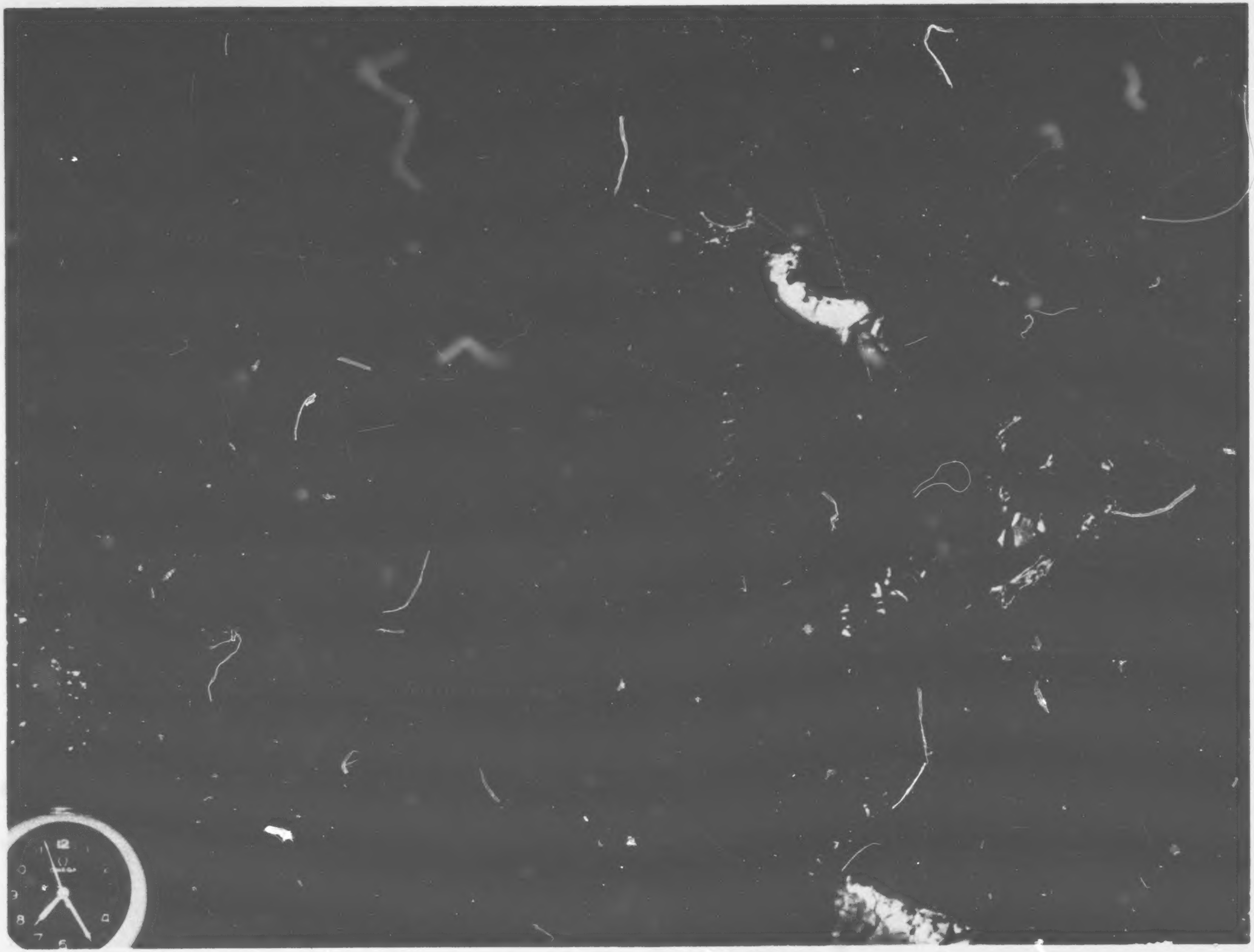

Fig. 28 A Skylab color infrared photograph of the Berry Islands.

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graphic film and magnetic tape) were returned to Earth with the crews. All data were processed at NASA's Johnson Space Center with copies made available to investigators and user agencies around the world. In total 141 investigations were made by individuals from 30 states, the District of Columbia, the Canal Zone, and 20 foreign countries.

Concurrent with Skylab overflights, aircraft and ground truth data were obtained for comparison purposes. These data were needed to correlate and calibrate spacecraft sensors and data. In time, it may be possible to eliminate this supporting process--at least in part.

The future holds even more promise for expanded sensor platform capability. The Shuttle Program with its integral Spacelab payload (produced by the European Space Agency) will allow a maximum of four investigators an opportunity to actively observe and sense the Earth from space. Planning has also begun for more advanced space stations and bases operating in low Earth orbit. These facilities will serve as greatly expanded, permanent platforms for domestic and international technologists using present systems as well as sensors yet to be developed. These functional platforms will provide a wealth of data for earth resources assessment purposes.

REMOTE SENSING PLATFORMS

Vocabulary - Define the following terms in detail.

DCP
LANDSAT
Ground Truth
Kilometers
Kilograms
Knots
Kilometers/hour
Photographic
Multispectral
Thermal Infrared
Microwave
Radar
Sensors
Drones
Dirigibles
DCS
Return Beam Vidicon
MSS
Waveband
Micrometers
EREP
Multispectral Camera
Infrared Spectrometer
Multispectral Scanner

Questions - Answer the following inquiries in detail.

1. Explain a data collection platform.
2. What is ground truth?
3. Discuss the concept of using balloon technology for remote sensing.
4. What is the general ground rule for aircraft platform sensors?
5. Discuss the difference between low, medium, and high-altitude aircraft remote sensing.
6. Discuss LANDSAT.
7. What three sensor systems does LANDSAT use?
8. Discuss the electromagnetic spectrum.
9. Explain the multispectral scanner system (MSS).
10. Explain return beam vidicon cameras (RBV).
11. Explain the data collection system (DCS).
12. Discuss the Skylab EREP program.

THE ANALYSIS OF REMOTELY SENSED DATA

Once an image has been obtained, its information must be discovered and understood before it can be applied to earth resources problems. In remote sensing this process is called data analysis. It refers to the act of examining data for the purpose of identifying surface objects and conditions and judging their significance. It may also be termed photointerpretation when applied to photographs or image interpretation when applied to images. This information may not be as precise as on-the-spot measurements. However, it covers large areas rapidly, can provide a three-dimensional (stereo) perspective, and frequently displays wavelengths invisible to the human eye. There are two major approaches -- visual, which uses the human mind, and electronic (or automatic), which uses the computer. These methods are often blended to achieve the final result.

Analysis Variables

The main functions of visual image interpretation are measurement, identification, and association. The length, area, height, and perimeter of objects can be determined accurately if the scale and distortion of the images are known.

A number of characteristics are combined in identification. The physical size, as determined from the scale and relative length, can distinguish a clump of grass from a tree, a row of dog kennels from an apartment complex, and a line of fence posts from telephone poles.

The shape of an object is essential to its identification. However, the interpreter sees only the planar projection, instead of the more familiar profile or oblique view. Thus, an inexperienced analyst may successfully classify the Pentagon in Washington, D. C., but may not recognize his own home or office building. This type of problem led to the development, in World War II, of interpretation keys. They showed typical military targets like trucks, trains, and artillery from the side and from above (see Figure 29). This same technique is used extensively today to help the forester differentiate various tree species (see Figure 30).

The trace of a building's shadow (Sun or radar) can also indicate its shape. Church steeples and bridge towers, almost invisible from above, may be revealed by their shadows. Geological structures like faults and drainage networks may be accentuated while other details are hidden in the darkness.

By far the most important clue in identifying an object is its color (tone in black-and-white). As a matter of fact, if an object does not contrast with its background or surroundings, it will never be found. The interpreter tries to identify the object through a difference in color or gray shade (tone). This contrast may change over wavelength, distance, time or season. For instance, hardwoods are often easier to distinguish in their fall colors. Color itself is usually more familiar to the analyst than tone and is, therefore, easier to work with.

Texture, the arrangement of tonal gradients affecting visual roughness, is also used in classification. As the scale decreases, trees blend into a forest mass whose texture is governed by the size, shape, color, and arrangement of the

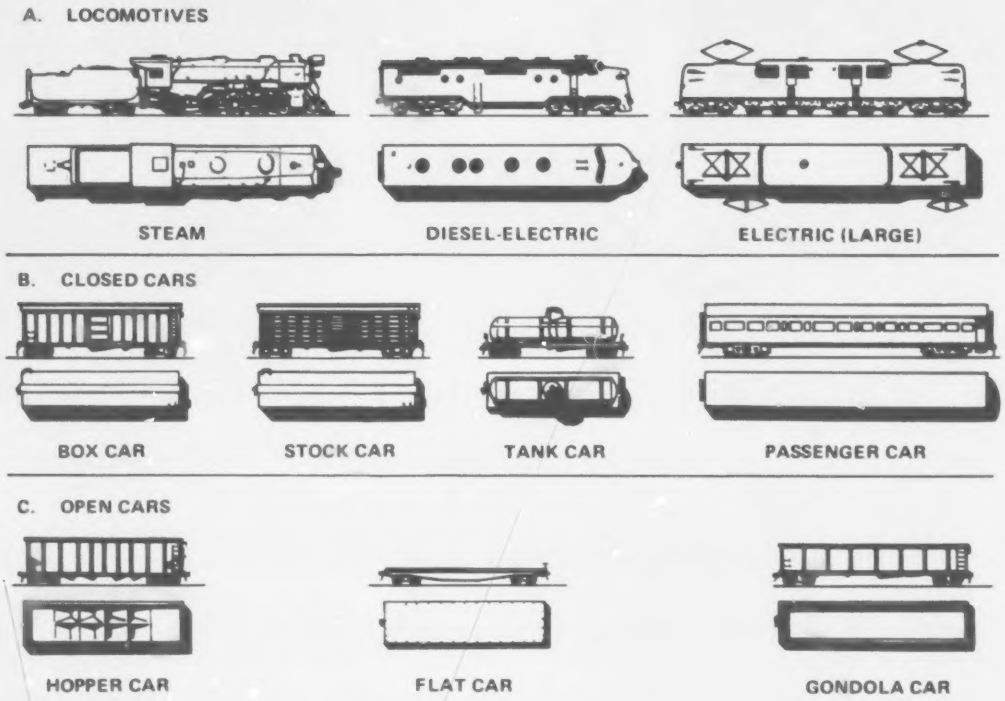
A. LOCOMOTIVES
STEAM
DIESEL-ELECTRIC
ELECTRIC (LARGE)
B. CLOSED CARS
BOX CAR
STOCK CAR
TANK CAR
PASSENGER CAR
C. OPEN CARS
HOPPER CAR
FLAT CAR
GONDOLA CAR

Fig. 29 Standard photointerpretation keys for railroad trains.

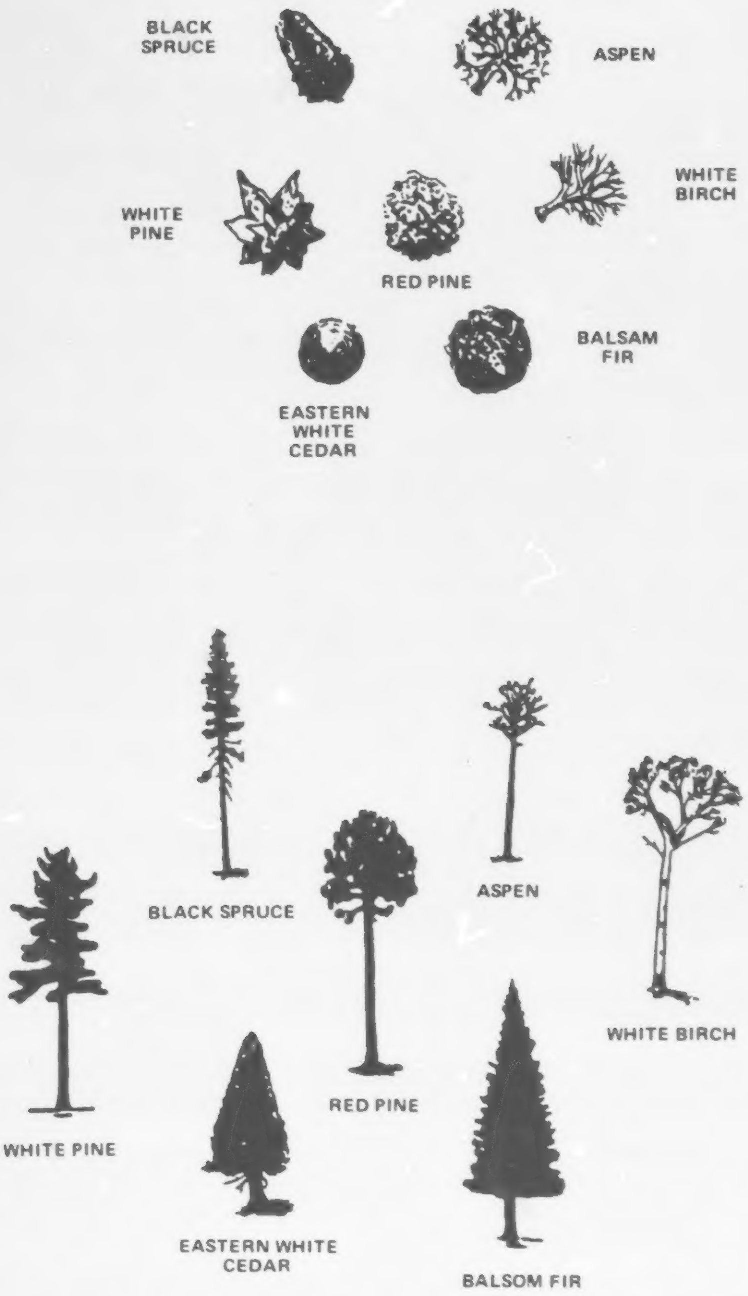
BLACK SPRUCE
ASPEN
WHITE BIRCH
WHITE PINE
RED PINE
BALSAM FIR
EASTERN WHITE CEDAR
BLACK SPRUCE
ASPEN
WHITE BIRCH
RED PINE
WHITE PINE
EASTERN WHITE CEDAR
BALSOM FIR

Fig. 30 Standard photointerpretation keys for trees.

individual trees. Thus, a mottled pattern representative of that type of forest community can be seen and identified.

Patterns of color and tone are also used in interpretation. For example, the loops of strip mining and terracing and the polygonal shape of buildings are important clues to the analyst.

A knowledge of the area and of the typical location of various facilities is of great value to photointerpreters. They need only consider plant communities and crops indigenous to the study area. They can expect to find hydroelectric plants near water and radar warning stations at high elevations. Field work (ground truth) is useful in strengthening the interpreter's knowledge and in verifying difficult identifications.

The combination and arrangement of features is also valuable in classification. Seeing the various parts of an industrial complex or a high school enables the analyst to deduce its identity. Such details may also provide extra information about the community.

Finally, in considering the components and surroundings associated with an object, the analyst must not forget resolution. If a detail is too small or lacks sufficient contrast, it may not appear on the image even though it is present on the ground. The lack of a detail may or may not affect the identification, depending on the image resolution.

Analysis Equipment

Analysts are aided in their work by various devices. To understand a scene, they may compare images from various spectral bands, dates, scales, and platforms. Analysts try to form a logical pattern in their search. They will bear in mind that they have certain visual limitations. These include possible deficiencies in eyesight, color perception or stereoscopic ability. Because the analyst is occasionally subject to perceptual errors, he uses various types of equipment to supplement his vision.

Simple viewing equipment includes light tables which illuminate transparent images and magnifying devices which reveal details. This equipment varies greatly in size. It may include many conveniences, like adjustable tilt and a selection of lenses. Devices for stereo viewing, which may also include magnifying lenses, range from pocket to table size. They aid the interpreter by presenting objects in their more familiar three-dimensional form. Figure 31 depicts a desk-top stereo viewer complete with optical viewing lenses, mirrors, and stereo overlapped imagery.

Other devices are used in image restoration. Faulty tonal balance caused by atmospheric and system effects can be overcome by certain developing techniques and averaging processes. When the plane hits an airpocket or tilts or is blown sideways by the wind, the resulting images may be distorted -- trapezoidal or rhomboidal in shape. Oblique photography shows a similar distorted perspective. The true location and relation of objects on the ground can be reconstructed from a knowledge of the geometry. This is sometimes aided by optical projection equipment. This equipment can alter the apparent scale as well as the proportions of an image. It can overlay the image on another picture,

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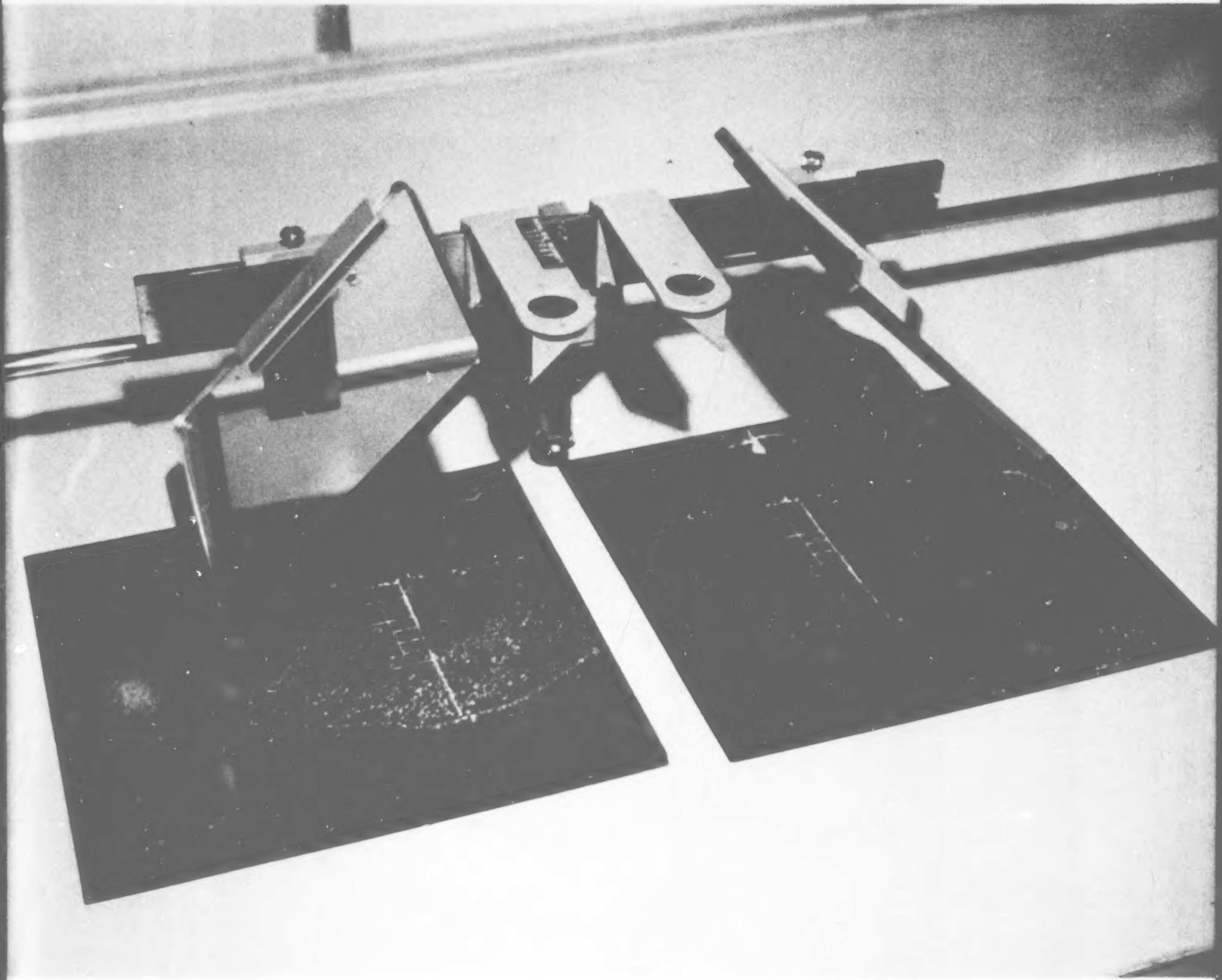

Fig. 31 A desk-top stereo viewer.

perhaps a map, and can align sumultaneous images in different spectral bands. Figure 32 shows an example of this type of equipment.

When the picture has been restored, still more equipment is available to help the analyst measure it accurately. Rulers, planimeters, and dot charts are applied to lengths and areas. Other devices are used to measure relative and absolute height.

Some devices measure the intensity of colors and tones through the film density or the recorded image radiance (gray level). These include manual reflectance or transmittance densitometers and scanning densitometers, which are part of a larger electronic system. These instruments often use the measured gray levels to perform an image enhancement. The image is either optically displayed, photographically reproduced, or recorded on tape. A device used for many of these functions is shown in Figure 33. It is called a scanning microdensitometer. An example of how this device is used is illustrated in Figure 34. Shown in the upper half of the figure is the negative on an x-ray of a hand -- with a broken finger. The lower half of the figure shows a scanned and computer-enhanced image. As is obvious, considerably more information is available in the enhancement than is evident on the original x-ray.

The density levels (gray tones) in one band may be contrasted or color-coded and reproduced. Images from different dates may be subtracted to show change. More sophisticated equipment with computer programming capability can smooth an image or enhance its edges. Filtering can accentuate rapid or slow variation. Geometric figures or particular dimensions can be selected and counted automatically if the tonal structure is simple. Overall patterns can be displayed for human analysis on complex images.

These same operations can be applied to multispectral imagery and, with the proper filtering, can be applied to color and color infrared photography. The black-and-white frames of multispectral photographs may be displayed through color filters to achieve a full color or false color representation. Figure 35 is an example of visual photo interpretation equipment used for these purposes. Figure 36 illustrates the results of combining the multispectral photographs of the Walt Disney World Theme Park shown earlier in Figure 12.

The presence of several spectral bands permits even more advanced enhancement. With various types of equipment, the bands may be added, subtracted, or ratioed. Various sets of spectral values may be identified and color-coded to explore their relation to ground phenomena. Statistical and pattern analysis may also be performed, as well as filtering, smoothing, and edge enhancement. Specially-designed image enhancement systems, including display panels, memory banks, and a roster of computer programs, are available for these tasks as are the standard large computers (see Figure 37). Figure 38 shows turbidity levels in Lake Okeechobee, Florida, which were generated using the equipment shown in Figure 37. Human interaction may be minimal in the rapid performance of routine tasks. It can be significant in the solution of some of the more complex remote sensing questions. Such advanced systems are valuable tools to the modern image analyst.

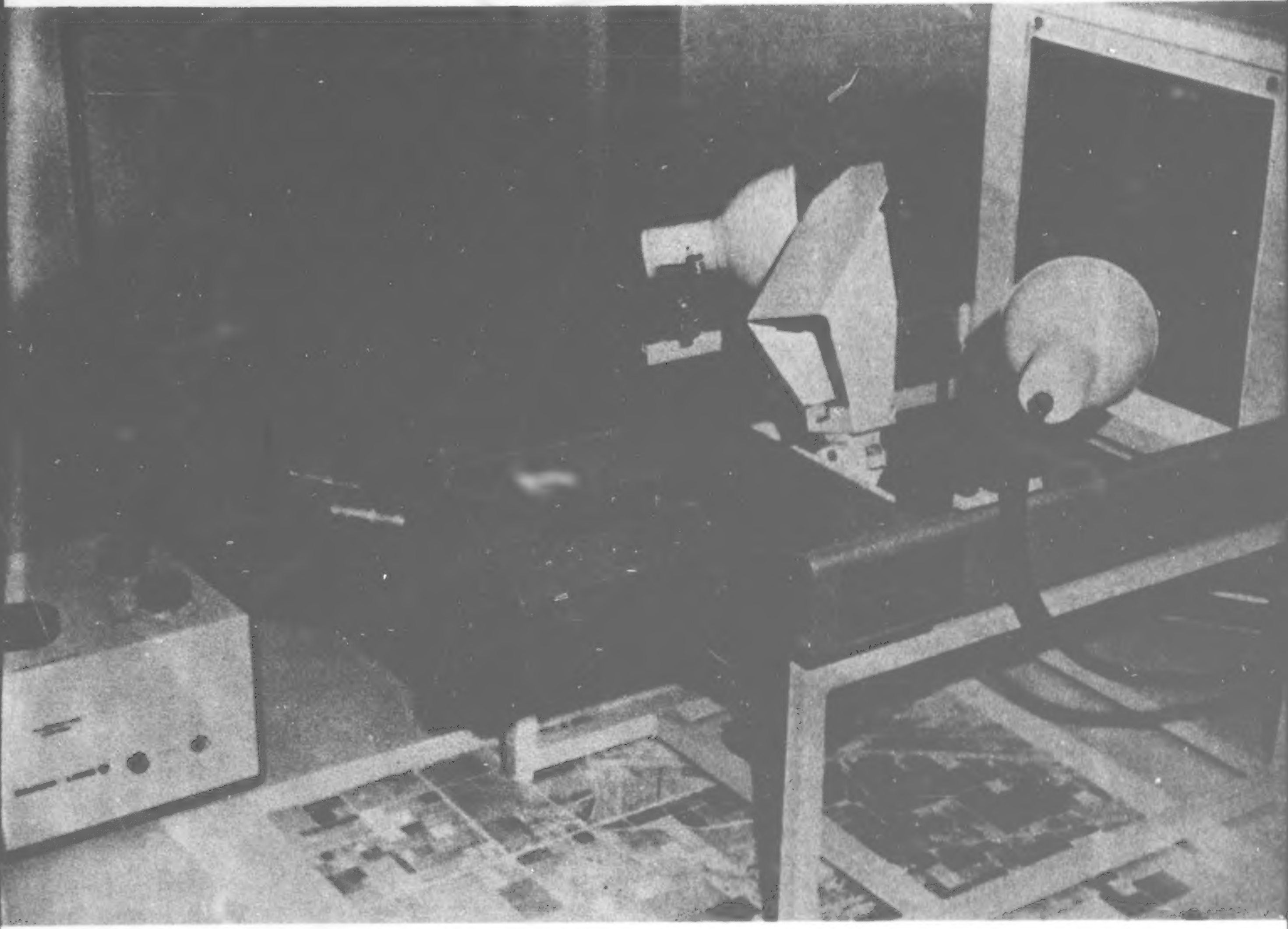

Fig. 32 Optical projection equipment (the Bausch and Lomb Zoom Transfer Scope).

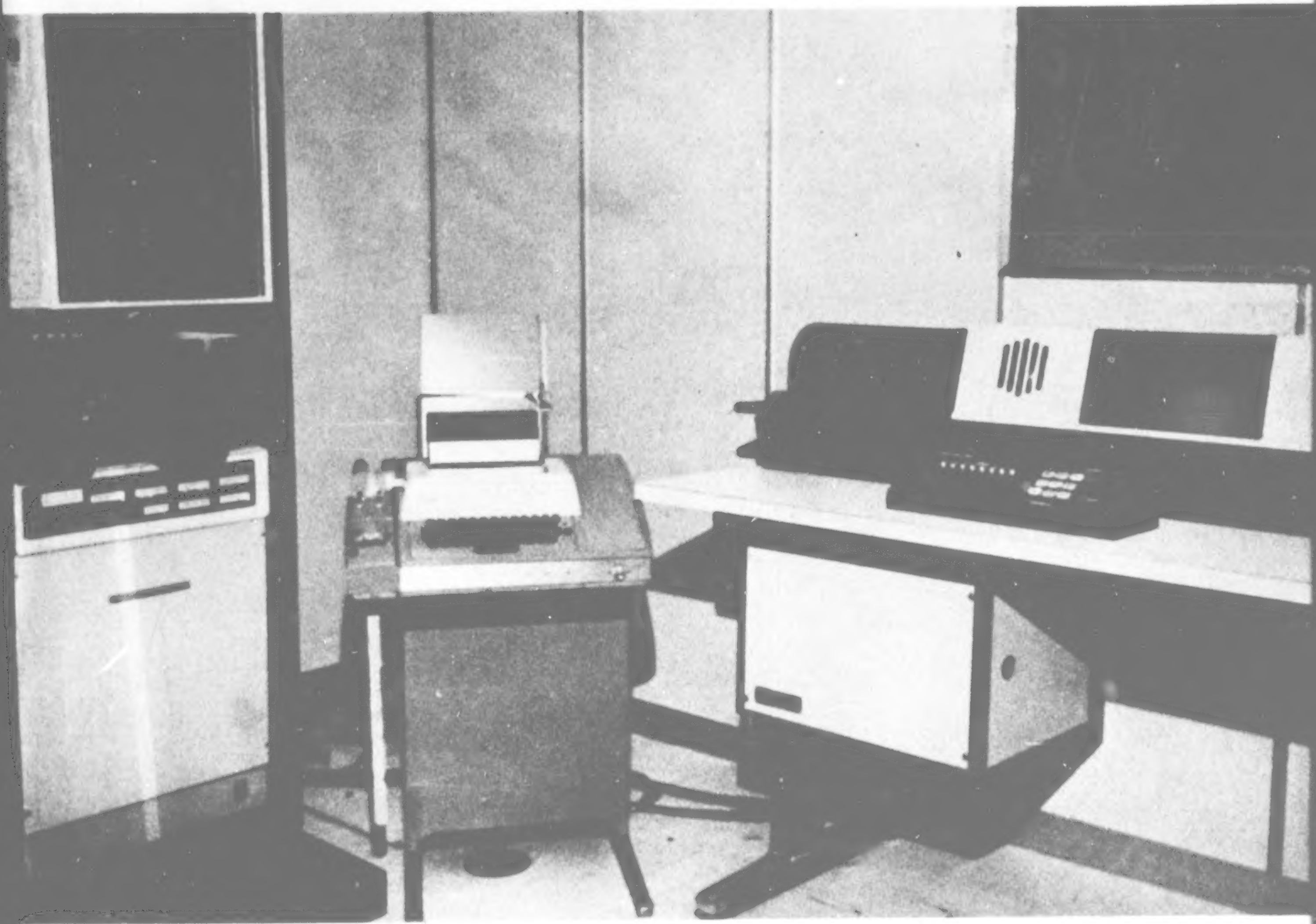

Fig. 33 A scanning microdensitometer.

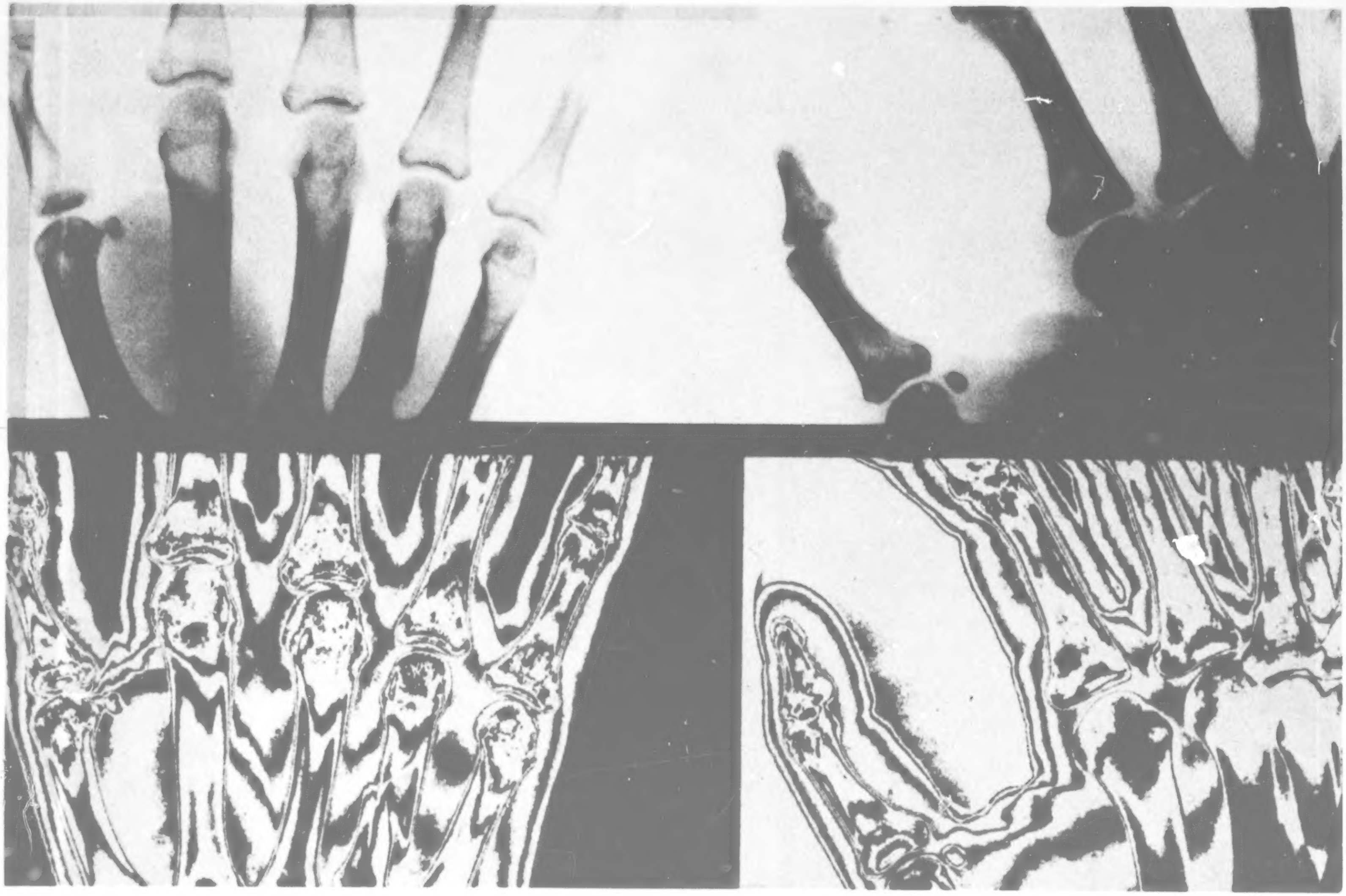

Fig. 34 The negative of an x-ray of a hand (top) and the same image enhanced by a scanning microdensitometer (bottom).

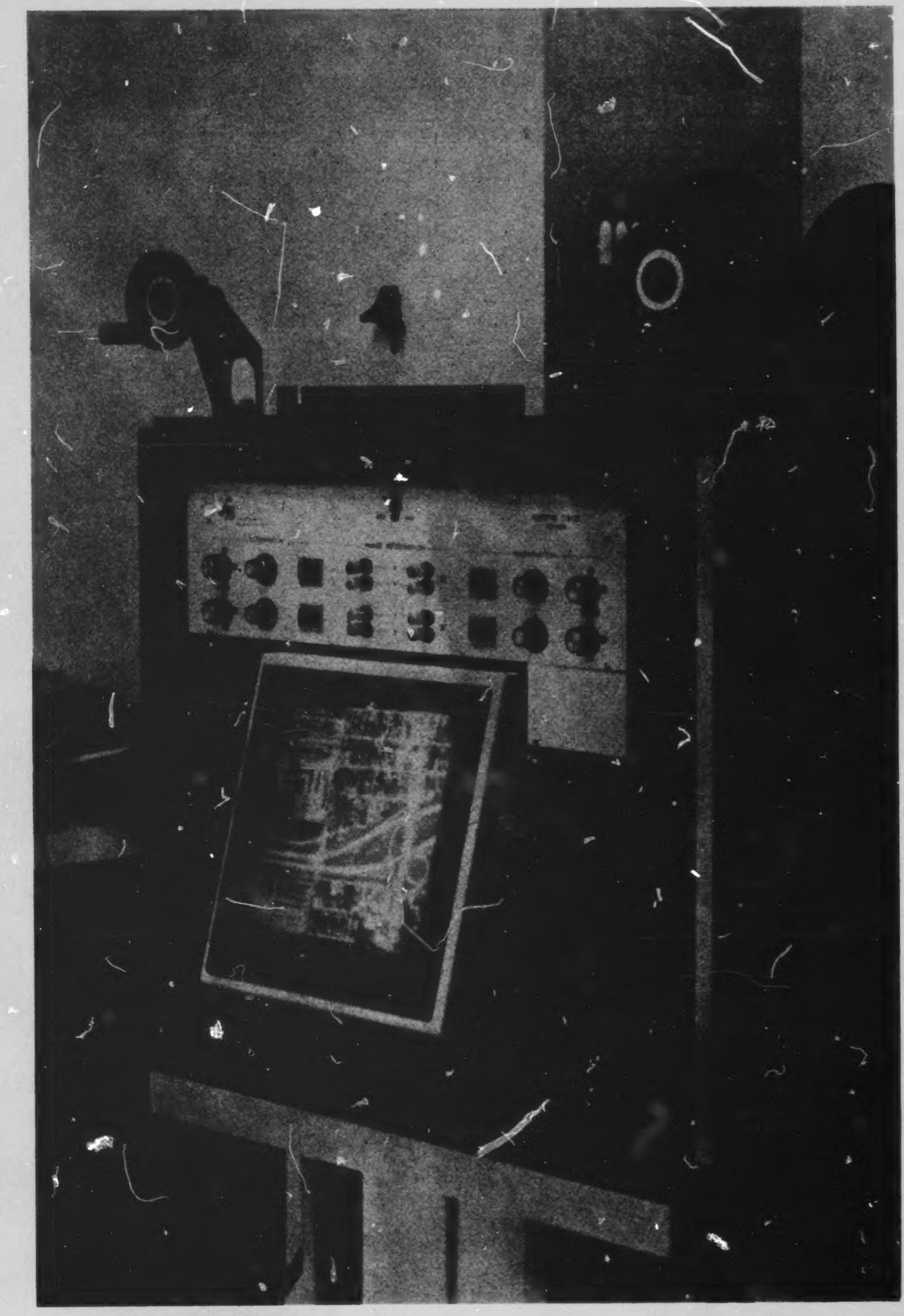

Fig. 35 A color additive viewer (for visual photointerpretation).

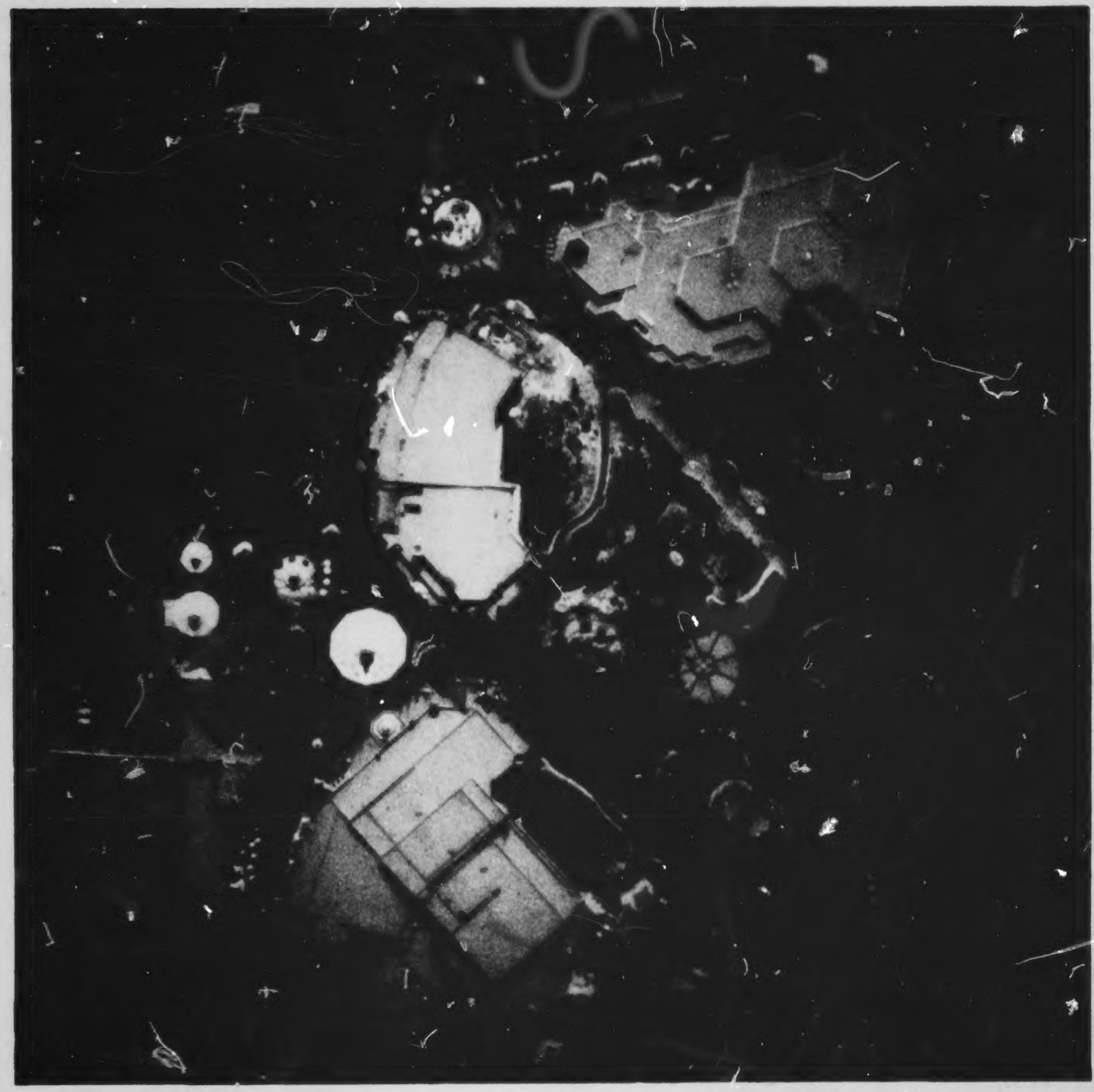

Fig. 36 Multispectral photographs of Walt Disney World displayed on the photointerpretation equipment shown in Figure 35.

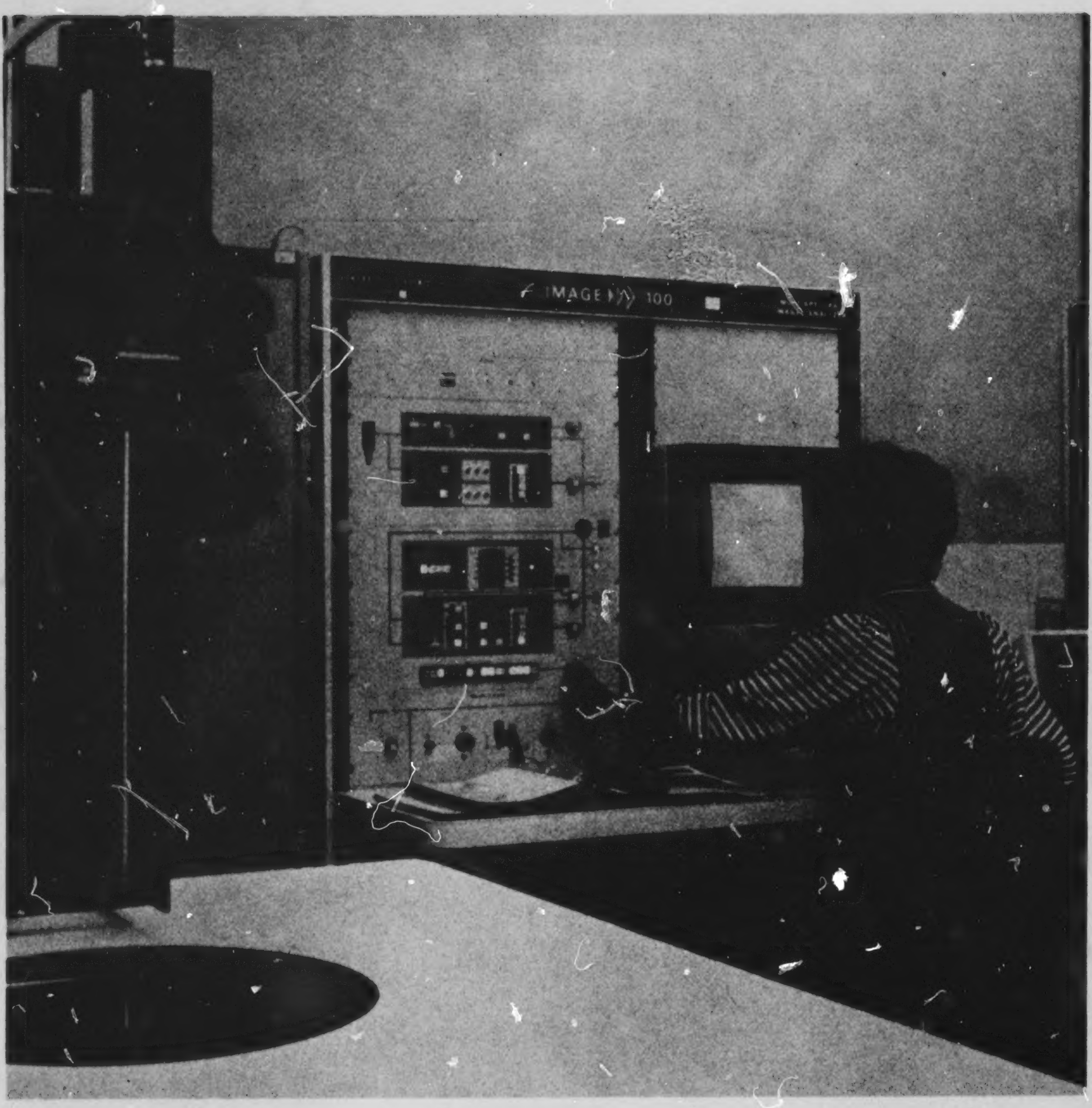

Fig. 37 A multispectral image analyzer (the General Electric Image 100).

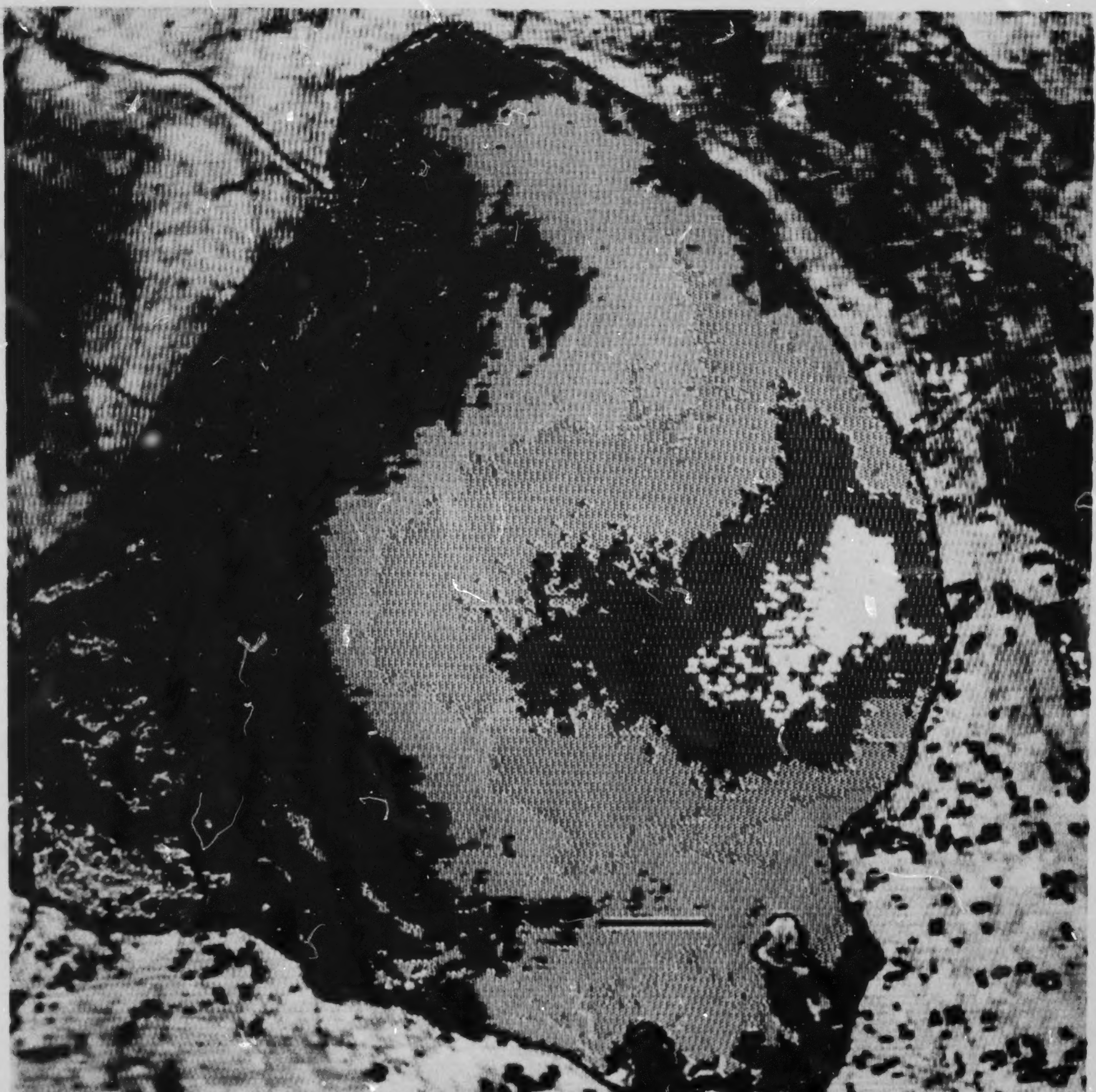

Fig. 38 Turbidity levels in Lake Okeechobee (Florida) generated on the equipment shown in Figure 37.

SUMMARY

The purpose of Section One has been to acquaint the reader with several significant aspects of remote sensing technology as it relates to earth resources applications. This new field of study is truly interdisciplinary in nature. It draws on all aspects of the physical sciences to understand our home planet. It may ohallenge the professional scientist as well as the beginning student. The various topics were presented with this thought in mind.

The evolution of remote sensing recorded the significant advances that have made present technology possible. In this history it was evident that photographic (camera, film, and filter) developments and electronic system advances have resulted in our current capabilities. Many of these advances were brought about by the necessities of war and later by the peaceful unmanned and manned aerospace program.

Applications of remote sensing to earth resources were described for such diverse areas as agriculture; mineral, water, and marine resources; and environment. These brief examples highlighted practical applications where both success and promise have been reported. Several problems and sensing variables faced by users of remote sensing technology were indicated. Much work needs to be done to expand application to current and anticipated problem areas. Then our natural resources can be correctly inventoried and properly conserved.

The nature of light was briefly described so that basic principles of sensor technology presented later could be understood. The Sun, our planet's primary source of electromagnetic radiation, was discussed. This source supports all life and provides the radiance detected by most of our remote sensing devices. Light was described as a form of electromagnetic radiation transmitted in waves from the source. It is affected by various factors in the atmosphere such as ozone, water vapor, clouds, and pollution particles.

Remote sensors of various types were described to provide an elementary understanding of the variety of sensor systems presently in use for remote sensing purposes. The cameras identified ranged from simple handheld units to complex multispectral systems. Non-photographic systems such as thermal, multispectral, and microwave scanners as well as television systems were breifly discussed.

Without platforms, earth resources sensors would be of little value. Surface observation, balloons, conventional and unconventional aircraft, and unmanned and manned spacecraft platforms were identified. These platforms represent the full range for sensors used in Earth observations. The relative simplicity of balloons and aircraft can be contrasted to space systems. Both have their optimum applications. Great strides have been made with unmanned and manned spacecraft systems. Increased applications have been found for large area data collection. This area shows great promise.

Finally, techniques and equipment necessary for the analysis of photographic and electronically sensed data were presented. Importance was given to the analysis variables of object size, shape, color, tone, texture, and area.

Equipment necessary to convert data into useful information was also identified.

In conclusion, a number of developments have occurred recently that have greatly expanded the ability of users and others to understand some of the variables of nature. Our knowledge continues to increase exponentially with few limits in sight. Our needs, however, seem to be outdistancing our technology. The challenge remains to develop new technology and to find additional applications for our existing technology.

THE ANALYSIS OF REMOTELY SENSED DATA

Vocabulary - Define the following terms in detail.

Data analysis
Stereo viewer
Spectral
Transmittance densitometers
Scanning microdensitometers
Planimeters

Questions - Answer the following inquiries in detail.

1. Discuss data analysis.
2. What types of variables must be considered in the analysis of an image?
3. Explain applications of photographic tones.
4. Explain texture.
5. Explain color patterns.
6. Why can local knowledge be important in photo interpretation?
7. Explain how a stereoviewer functions.
8. What is density?
9. What instruments are used to measure density?
10. What is false coloring?

SECTION TWO

SELECTED READINGS

FOREWORD

This section consists of a representative collection of selected readings organized by discipline. The primary sources of these readings are various symposium proceedings and journals. Several hundred papers were reviewed before the final sixteen were selected, and each is presented in its original and unedited version, except that some vocabulary terms, which are important to a full understanding of remote sensing science and its application, have been capitalized for emphasis. The student should familiarize himself with these words and their use. While several criteria were used for selection purposes, of primary importance was the application of technology to "real world" problems. Since earth resources problems are local, regional, and global in nature, a fairly wide distribution of investigations was selected.

After reading these selected articles, the student will become familiar with the vocabulary and will be able to answer questions and discuss related topics. It should become obvious that while researchers seek simple solutions to scientific problems, nature is not always a cooperative partner. The dynamic equilibrium of nature is maintained by complex interrelationships. Nature's forces, actions and reactions, and other variables often require highly sophisticated technological solutions. For this reason, any collection of readings will be somewhat outdated by the time it is selected, published, and available for use. This should not, however, lessen the importance of these articles.

Exposing students at the senior high school level to earth resources investigations through remote sensing will help them to understand the application of scientific principles in earth resources research. It will still be the student's responsibility to integrate basic science with technology. The variety of findings and judgments reported in these selected articles by investigators from universities, state and federal government agencies, private industry, and research corporations will help this integration process.

Students should recall from the discussion of remote sensing platforms (Section One) that the Earth Resources Technology Satellite-1 was renamed LANDSAT-1 on January 13, 1975. LANDSAT-2 was launched on January 22, 1975. Throughout many of the articles in this section, both ERTS and LANDSAT are used to identify these satellites.

USEFULNESS OF LANDSAT DATA FOR MONITORING PLANT DEVELOPMENT AND RANGE CONDITIONS IN CALIFORNIA'S ANNUAL GRASSLAND

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ABSTRACT

The California annual grasslands are economically important rangelands. They do, however, present some problems to livestock producers due to the shortlived nature of the forage. Livestock production can be maximized on these lands if the ranchers can receive a better idea of when, how much, and how long forage will be available.

The investigators established a net work of sampling sites throughout the annual grassland region to correlate plant growth stages and forage production to climatic and other environmental factors. Plant growth and range conditions were further related to geographic location and seasonal variations.

A sequence of LANDSAT data was obtained covering critical periods in the growth cycle. This data was then analyzed by both photo-interpretation and computer aided techniques. Image characteristics and spectral reflectance data were then related to forage production, range condition, range site and changing growth conditions.

As a result of this study, it was determined that repeat sequences with LANDSAT color composite images do provide a means for monitoring changes in range condition. LANDSAT SPECTRAL RADIANCE data obtained from MAGNETIC TAPE can be used to determine quantitatively the critical stages in the forage growth cycle. In addition, a COMPUTER RATIOING technique provided a sensitive indicator of changes in growth stages and an indication of the relative differences in forage production between range sites.

The anticipated benefits from LANDSAT monitoring of annual range vegetation include: (1) more accurate determination of germination and drying periods for planning movement of grazing animals to or from annual grassland ranges; (2) predictions of the remaining length of the green feed period made early enough to plan more efficiently for alternative sources of livestock feed; (3) comparison of conditions and relative forage production between grazing areas within a season, and comparison of condition and productivity for a given area between seasons; (4) determination of time when dry forage creates a fire hazard in order to better allocate men and equipment for fire suppression; and (5) assess extent and location of grazing areas influenced by abnormal climatic conditions, be it drought or abundance of forage.

INTRODUCTION

NASA's Earth Resources Technology Satellite (LANDSAT -1) launched July 23, 1972, provided an unique capability for regional monitoring of forage plant development within

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rangeland environments. The repetitive coverage, the synoptic view and the opportunity for acquiring real time imagery combine to make LANDSAT data a valuable input for determining seasonal range conditions, and forage production. A LANDSAT investigation for the Bureau of Land Management (United States Department of Interior) conducted at the University of California, Berkeley, examined the feasibility of using LANDSAT data to: (a) monitor growth and development of forage plants in the Annual Grassland in California; (b) determine the relative amount of forage produced within and between growth seasons for a given area; (c) map grasslands with different forage production, and (d) predict forage condition and production using models which incorporate ground forage samples, SPECTRORADIOMETRIC and climatic data. The study was conducted primarily during the 1972-73 growth cycle, with subsequent comparison of LANDSAT data during the 1974-75 growth cycle. The study area includes the annual grassland range seen within the LANDSAT images of San Francisco Bay; however, observations and measurements of plant growth and spectral data were made at two test sites; Pinole, located within a 50 cm rainfall zone, 10 miles northeast of Berkeley, and San Luis Reservoir, located within a 25 cm rainfall zone along the shore north of San Luis Reservoir located about 10 miles west of Los Banos, California.

CALIFORNIA ANNUAL GRASSLAND

The annual rangeland in California is located primarily in the foothills of the Coast Range and Sierra Nevada Mountains. They are economically important by virtue of the area they occupy (8 to 10 million HECTARES) and the amount of forage they produce. These ranges are characterized by a complete cover of grasses, clovers, and forbs, which germinate in autumn following a sufficient amount of rainfall to adequately wet the soil. Foliage growth is generally slow through the winter, followed by accelerated growth during the late winter and early spring. Plants mature, flower and subsequently dry during the spring in response to depletion of soil moisture.

Within the annual grassland range there are various grazing regions which differ in PHYSIOGRAPHY, GEOMORPHOLOGY and climatic regime. As a result they also differ in species composition, rate and timing of plant development, season of use by grazing animals, plant density, structure and productivity. (Talbot, Biswell, Hormay, 1939; Biswell, 1956; Heady, 1958). Because of seasonal variations in weather patterns within and between the different grazing regions, the condition and production of forage are also variable (Heady, 1958). The lowest forage producing areas are in the low rainfall zones (13-15 cm) in the southern portion of the annual grassland range, whereas the highest producing areas are in central California (50-75 cm rainfall zone). Forage production in the northern portion of the annual grassland range is generally 30% less than the central portion due to lower temperatures despite the higher amounts of rainfall it receives (100-125 cm) (James, 1969).

Within any given grazing region forage production and the length of the green growth period vary from year to year depending upon the climate pattern. Production also varies from site to site depending upon elevation, slope, aspect, the climatic regime, and various physical, chemical, and biological characteristics of the soil. Generally, sites with northeast exposure remain green longer and have higher forage production compared to sites on a southwest exposure. Similarly, sites with deep, fine textured soils, having high water holding capacities, remain green longer and have higher forage production than sites with sahllow, coarse textured soils. Plant species which occur more frequently on the productive sites include:

wild oats (Avena fatua, A. Barbata); soft chess (Bromus mollis); ripgut brome (Bromus rigidus); wild barley (Hordeum); Italian ryegrass (Lolium multiflorum); bur clover (Medicago hispida). Forage species commonly associated with less productive range sites include: foxtail fescue (Festuca megalura); red brome (Bromus rubens); filaree (Erodium botrys, E. cicutarium); clovers (e.g. Trifolium microcephalum); wild barley (Hordeum); annual forbs; bur clover (Medicago hispida).

Cattle and sheep are the primary grazers of annual rangeland. Approximately 50 to 80 percent of the 5.2 million cattle and 1.1 million sheep in the state spend a portion of their lives on the annual range. Grazing occurs primarily during the winter and spring months, but some livestock operators retain their animals on the dry annual rangelands throughout the summer. Generally, however, once the forage has been depleted or dried, resulting in lower nutritive quality, (Hart, Guilbert, and Gross, 1932) the animals are moved from the range to green pastures in the Central Valley, to feedlots or to perennial summer ranges.

RANGE CONDITIONS DURING THE 1972-73 GROWTH PERIOD

The first rains of the 1972-73 season fell in late September causing germination of the annual forage throughout the northern half of the state. The second rains occurred in mid-October causing further germination to the south over approximately half of the remaining range where GERMINATION had not occurred. Finally, rains during the first and second weeks of November caused germination throughout the remaining annual grassland areas. This southward progression of germination was monitored by the LANDSAT passes in October and November. By April, the forage in the lower rainfall belts had reached maturity and had begun to dry. Drying occurred first along the east side of the Coast Range and gradually progressed northward and to higher elevations during May. By the end of May most of the annual forage in the state was dry. LANDSAT imagery obtained during this time period made it possible to monitor the location and progression of drying throughout many sites in the California annual rangeland. (Carneggie & DeGloria, 1973).

METHODS

COLLECTION OF GROUND DATA

A network of sampling sites was established throughout the state from regions representing different climatic regimes. Two of the sites were the Pinole and San Luis Reservoir Test Sites seen with the LANDSAT image of San Francisco Bay. Measurements and observations of the annual plants were collected between October 1972 and June 1973. At each site observations of PHENOLOGICAL stage, for example, the time periods when germination, maturity and drying occurred, were recorded. Ground photographs were taken periodically at each sample site to provide a permanent record of the phenological stage of plant growth, and the relative condition (greenness or dryness) of the plants.

At each test site two or three replicate samples of plant weight, height, and SPECTRAL REFLECTANCE were obtained periodically from grazed and ungrazed plots located on several different sites. Plant weight estimates were obtained by clipping the forage to ground level within a one square-foot quadrat. The dry residual material from the current growth was oven dried and weighed. Plant height measurements were the average length of the forage of INFLORESCENCES within the sample plots. Graphs of forage production at grazed and ungrazed plots at Pinole and San Luis Reservoir appear in Figure 1. These graphs show the difference between sites located in different rainfall zones in terms of date of germination, amount of forage produced under moderate grazing and without grazing, and time when production ceased, which generally coincided with the drying period.

Ground spectral reflectance measurements were obtained at the Pinole Test Site throughout the growing period; however, spectral readings were made only during the rapid growth period at other sites. Spectral readings were corrected for sensitivity throughout the spectrum from 400 nm to 1200 nm. Corrections were not made for sun angle, season of the year, or time of day because the primary use of the data was to form spectral reflectance ratios which were compared for the different dates of measurement. Generally the spectral reflectance readings were made just prior to the the removal of a forage sample and close to highest sun zenith. The reflectance ratios were formed by dividing reflectance readings in the near infrared (800 nm) by the reflectance readings in the red (675 nm). This ratio has been shown to be highly correlated with green biomass (oven dried) in the short grass prairie region (Tucker, Miller, and Pearson, 1973); thus, similar studies were performed in the California annual grassland to test its applicability. Roberts and Gialdini (1973) have shown that infrared reflectance decreased while reflectance in the red band increases as annual forage matures and dries, corresponding to a declining amount of green biomass. Ratios formed by reflectance in the infrared and red bands would decrease with declining amounts of green biomass. Other LANDSAT investigators have also shown correlations between green plant biomass and LANDSAT reflectance data in bands 7 and 5 (Rouse, J. W. et. al, 1973; Maxwell and Johnson, 1974). Figure 2 shows the ground spectral reflectance ratio curves, green forage production curves (oven dried), and phenological data at the Pinole Range Test Site.

LANDSAT IMAGERY ANALYSIS

Cloud-free LANDSAT-1 imagery of the San Francisco Bay Area was available on October 6, October 24, 1974, and January 4, January 22, April 4, April 22, May 10, May 28, and June 15, 1973. This imagery provided the opportunity to observe the initiation of germination, the peak of the growth period, and the progression of maturity and drying. LANDSAT-2 imagery taken over the same area in January 1975, provided an opportunity to compare seasonal development between growing seasons.

Nearly all of the cloud-free LANDSAT imagery which provided coverage of the ground sampling sites was processed to color composites simulating color-infrared images. Color Plate I shows a sequence of LANDSAT color composites of the test site located in Pinole Valley, east of Berkeley. The accompanying ground photographs (Color Plate II) were taken at approximately the same time as the LANDSAT images and document the changes in appearance and condition of the forage during the 1972-73 growth period. Hand held vertical ground photographs were also taken over each sample site to provide a pictorial record of the stage of plant development corresponding to the various dates of LANDSAT overpasses. The ground photographs along with the written record of phenological stage provided the ground references used to evaluate the changing appearance of the annuals as viewed on the LANDSAT color composites. The LANDSAT images provide a reference base for recording and interpreting range condition throughout a large region, and for making comparisons of range conditions in previous or subsequent years. The opportunity provided by LANDSAT imagery to accurately and unbiasedly compare range conditions between grazing regions in any given year, and to compare conditions for a given site between years is fundamental to the development of an operational range monitoring system.

LANDSAT DATA TAPE ANALYSIS

LANDSAT tapes for all cloud-free passes over the San Francisco Bay Area, which contain the Pinole and San Luis Reservoir Test Sites, were acquired in order to analyze the spectral data in each of the four spectral bands (4, green; 5, red; 6, near-infrared; 7, near infrared). The objectives for analyses were (1) to determine if LANDSAT spectral data provide a reliable means for assessing forage conditions, and (2) to examine the relationship between LANDSAT spectral data, ground spectral data, PHENOLOGY and forage production curves. The LANDSAT tapes analyzed included: July 26, 1972; August 13, 1972; October 6, 1972; January 4, 1973; April 4, 1973 ; April 22, 1973; May 10, 1973; and May 28, 1973. On each of the magnetic tapes, the spectral radiance values associated with two areas measuring 6 x 6 picture elements in size, (which corresponded with the Pinole and the San Luis Reservoir Test Sites) respectively, were analyzed. No corrections were made for atmospheric variables; however, each date of imagery analyzed was a relatively clear day without any apparent clouds. The average and standard deviation were computed for both areas for each date, and for each MSS band. Figures 3 and 4 show the graphs of LANDSAT spectral radiance plotted over time for the Pinole and San Luis Reservoir Areas. Figure 5 shows the plot of the spectral reflectance ratio of band 7 and band 5 for Pinole and San Luis Reservoir Test Sites.

RESULTS

MANUAL ANALYSIS OF LANDSAT IMAGERY FOR MONITORING PLANT GROWTH AND RANGE CONDITION

Color Plants I and II show LANDSAT images (color composites) and ground photographs taken at eight dates during the 1972-73 growth period of the annual rangelands in Central California. This photo sequence shows the foothills at the Pinole Test Site in a dry condition on October 6, 1972, prior to complete germination. Sufficient rainfall had fallen on September 26, 27, 1972, to cause partial germination of annuals on the bottomland sites. However, evidence of this partial germination is not present in either the ground photo or the LANDSAT image. New plants were obscured by dry residual material from the previous season as seen on the LANDSAT image. where the foothills appear a tan color characteristic of dry vegetation. A second storm occurring between October 7 and 13, 1972, produced more than sufficient rainfall to cause complete germination of the annuals in this region, so that by October 24, 1972, the foothills appeared green with the new growth of the annual plants. This initial transformation in the appearance of the annual rangeland is dramatically illustrated by the LANDSAT image taken October 24, 1972, where the foothills around the Pinole Test Site appear reddish, corresponding to the presence of a new cover of green plants. Initially, growth was rapid, but the cold winter temperatures eventually suppress the growth rate. The January 4 photographs (LANDSAT and ground) show a subtle change from those of October 24, corresponding to a relatively small increase in cover and volume of annual plants. Cattle were introduced to this rangeland during the last week of November; thus, the appearance of the range in January is affected by the winter conditions affecting growth, by moderate grazing pressure, increased soil moisture and low sun angle.

In the grazing region containing Pinole Test Site, warming temperatures caused increased growth beginning in February. Growth remained rapid reaching peak foliage development in mid April. In grazing regions to the south the rapid growth period started earlier and was much shorter relative to the Pinole area.

The LANDSAT and ground photograph taken April 4, 1973, shows the foothills appearing at near their maximum green stage, considering the different stages of development on the different sites (bottomland, midslope and upland) which characterize this grazing region. The intensity of red coloration seen on the LANDSAT image (April 4) indicates the annual range is near its peak green condition. It should be recognized that at this time, plants on the upland sites had already formed inflorescence, while plants on the midslope and bottomland sites had inflorescence which had only recently emerged or were just emerging, respectively.

By April 22, forage plants on the upland sites had begun to dry, while plants on midslope and bottomland sites had developed inflorescence. This change is noted on the LANDSAT image by a subtle shift in color from red to red-orange for the Pinole Test Site. The first indication of widespread drying of the annuals can be noted in the grazing region south and east of the Pinole Site. Here the foothills appear a yellow-orange color characteristic of widespread drying of annual vegetation.

By May 10, all vegetation on upland sites in the Pinole Test Site had dried. Many of the plants on the midslope sites had also dried, and plants on bottomland sites had well developed inflorescence with foliage remaining green. On the corresponding LANDSAT image the Pinole Range Site appears an orange color. Along the East side of the Coast range the annuals associated with the low rainfall--foothill areas (including the annuals at San Luis Reservoir), had completely dried as evidenced by the yellow color of these areas on the imagery. By May 28, most of the annuals associated with upland and midslope sites had dried, and drying had begun on bottomland sites. The LANDSAT image shows the foothill area around Pinole as a yellow orange color. Note that on this LANDSAT image most of the annual vegetation on the foothills to the east and south had already dried. By June 15, all of the annual plants associated with the foothills in the Pinole Test Site had dried. The LANDSAT image accurately depicts this condition, as evidenced by the yellow or straw colored appearance of the foothills throughout the grazing region. The colors of the dry rangeland are much brighter than those seen on the October 6, LANDSAT image because there is much more residual dry material. Throughout the summer, continued grazing use and/or natural deteriorating would cause the rangeland to return to an appearance very similar to that seen on October 6, 1972.

The sequence of LANDSAT images with the corresponding ground photographs that show range conditions in more detail, demonstrate that if LANDSAT images are cloud free during critical periods of the growth cycle of the annual range, one can monitor the timing of these growth states and accurately assess the condition of the range plants. The growth stages which are critical are: the period of germination, the time of peak foliage development which coincides with the time that most of the plants have inflorescence in the dough or green stage, and the period of drying. To the extent that these stages can be documented, managers can determine the length of the green feed period, the time when the foliage is near its peak nutritional quality, the time when drying occurs, which reduces the quality of the forage, fuel hazard, and the availability of green forages. The time when these phenological events occur in relation to the expected or average time of occurrence can signal whether the current forage crop is below average or above average; hence, forage production can be inferred from a prior knowledge of the average timing of growth stages. Moreover, the large area coverage of LANDSAT provides a means for determining the progression of growth in the different grazing regions of the California Annual grassland. Thus, in any given year, drought affected areas or areas receiving below normal amounts of rainfall, (hence lower forage production) can be located, and the areal extent of these areas determined. Similarly, LANDSAT images can also show rangelands where above normal rainfall distributed throughout the growth cycle has resulted in a prolonged green feed period resulting in greater forage production and livestock weight gains.

Thus, manual interpretation of LANDSAT color composites can accurately determine the timing of three critical growth stages. However, cloud coverage during any of these periods substantially reduces the advantage of LANDSAT for acquiring this information in comparison to conventional methods. To reduce the possibility of acquiring unsuitable coverage during the critical stages, additional satellites or more frequent coverage would be required. As an alternative, light aircraft could be used for reconnaissance purposes during critical observation periods if cloud coverage was known to obscure the rangeland at the time of LANDSAT overpasses. In spite of the problem presented by cloud coverage, cloud-free images permit one to estimate the portion of rangeland which has already dried, rangeland which is drying, and rangeland which is still green. Such an assessment can be used to predict the amount of animal movement from the range, and determine where the movement originates. Moreover, one can determine which areas are still green and make predictions regarding the amount of time that the forage would remain green, given particular weather conditions. Finally, maps showing different seasonal conditions could be produced each year for comparison with known conditions on previous and subsequent years, and statements regarding present conditions (greenness or dryness; or productivity) in relation to past conditions could be made. The value of these interpretations can be realized through better planning, predictions, and wiser decisions regarding rate and location of animal movement, need for supplemental feed, amount and location of residual dry material which causes critical fire hazard, and amount and quality of green feed in relation to (a) previous years or (b) an established normal.

Color Plate III shows a LANDSAT-2 color composite of rangelands adjacent to the San Francisco Bay Area, taken on January 24, 1975. When compared with the LANDSAT-1 image dated January 4, 1973 in Color Plate I, one can readily detect differences in the colors associated with the rangeland vegetation . The dull pink colors in the LANDSAT-2 image (January 24, 1975), correctly signify that forage growth had not progressed as rapidly for the 1974-75 growth season compared with the 1972-73 growth season. In fact, rainfall during the 1974-75 season was 50-60% below normal at the time the LANDSAT-2 image was taken. Not only was plant development slow, but forage production was also below normal. Ranchers were obliged to reduce number of livestock and/or provide feed supplements for a longer period of time. The important value of the LANDSAT data is in providing a permanent, unbiased record for comparing range conditions at approximately the same time period in two different growing years.

MONITORING PLANT GROWTH AND RANGE CONDITIONS: QUANTITATIVE ANALYSIS OF LANDSAT TAPES AND GROUND SPECTRAL REFLECTANCE DATA

Ground spectral reflectance data - Throughout the 1972-73 growth season ground spectral reflectance (reflected radiant energy) measurements were made at frequent intervals at the Pinole Test Site. For the most part, reflectance measurements were made at randomly selected locations on both grazed and ungrazed bottomland, upland and midslope sites. Once a SPECTRAL REFLECTANCE MEASUREMENT had been obtained, the plot was clipped, and the weight of the forage recorded. The SPECTRAL REFLECTANCE VALUES corresponding to 675 and 800 NANOMETERS were formed into a ratio and this ratio plotted over time for the growth season. Figure 2 permits a comparison of the spectral reflectance ratio curves for three sites in the Pinole Test Site with the corresponding green forage production data (oven dried) associated with the same range sites.

The similarity between the spectral reflectance ratio curve and the green forage production curve can be seen in Figure 2. The spectral reflectance ratios increase dramatically at the outset of the growth season corresponding to the period when germination has occurred. That the ratio for the upland site was so high can be explained in part by the complete cover of new vegetation and partly by the reflectance characteristics of the species occupying these sites. The ratios decrease markedly at the end of the growth season corresponding to the drying period prior to complete senescence of the forage crop.

The time when the spectral reflectance ratios peak is of particular importance. For each site, both grazed and ungrazed, the peak of the ratio curve occurs at the growth stage corresponding to early inflorescence development. This growth stage occurs just prior to the time when foliage production is at its peak and the nutritive quality of the forage is also near maximum. It should be noted that the ratio curve peaks first for the upland site, followed by the intermediate and then the bottomland site. The time of these peaks and the order of their occurrence are consistent with the documented phenological ground conditions at these sites which are diagramed in Figure 2.

Finally, the relative difference in magnitude of the peaks of the ratio curves correspond with the relative difference in the forage production curve peaks associated with the three respective sites. These data indicate that the spectral reflectance ratio (800/675) is a sensitive indicator of the relative difference in green forage when different sites are compared. In addition it appears that the peak of the ratio curve coincides with the period when the forage is at its peak green stage, just prior to maximum foliage production.

LANDSAT spectral reflectance data - LANDSAT spectral radiance data for the Pinole and the San Luis Reservoir Test Sites was extracted from LANDSAT computer compatible tapes. The average radiance value and the standard deviation of this mean for the two 6 x 6 picture element areas were determined from LANDSAT tapes acquired on August 13, and October 6, 1972, and January 4, April 3, April 22, May 10, and May 28, 1973. The average radiance for each of the four MSS bands is plotted against the date of acquisition in Figures 3 and 4 for the Pinole Test Site and San Luis Reservoir Test Site, respectively. These two Test Sites were selected for comparison because they occur within the same LANDSAT frame, and because they are in two different rainfall zones. The Pinole Test Site is in a 50 cm. rainfall zone having a green feed period of about 7 1/2 months; whereas, San Luis Reservoir Site is in a 25 cm. rainfall zone having a green feed period of about 6 months.

An examination of the LANDSAT radiance curves for Pinole and San Luis Reservoir Test Sites reveals that the radiance values for all spectral bands decreases from the dry summer stage to the period of first rainfall or germination. Once the annual plants have germinated the infrared bands 6 and 7 increase in reflected radiance in response to increasing cover and density of forage. The visible bands 4 (green) and 5 (red) decrease in REFLECTED RADIANCE due to absorption of these wavelengths by the plants, and remain fairly constant through the slow growth period during the winter months. When growth begins to accelerate in late winter and early spring, reflected radiance in the infrared wavelengths increases rapidly while the visible wavelengths increase very slowly. Both infrared radiance curves (bands 6 and 7) peak when inflorescence are developing. This is also when the forage is at its peak green stage, just prior to maximum green forage production. The radiance curves for the infrared bands decrease in response to the drying of the annual vegetation. LANDSAT radiance for bands 4 and 5 increases rapidly during the time period coinciding with inflorescence maturity and the onset of drying on the shallow sites. Approximately 1 month after radiance in the infrared bands had reached a peak, radiance values from bands 4 and 5 cross over, due to the more rapid increase in radiance of band 5 compared to band 4 during this period. This rapid increase in band 5 radiance is correlated with the period of rapid drying of the annual forage. Moreover, this cross-over period occurs when forage on approximately half of the range sites is dry, while the other half is green and maturing. Once all the annual vegetation has dried, the radiance curves return to approximately the same level as those for the summer stage in the previous year. The late spring (1973) radiance levels are slightly above the radiance levels for the previous summer, (1972) because a greater amount of dry residual material remains on the sites at the onset of the summer of 1973.

The shape of the LANDSAT radiance curves is similar for the Pinole and San Luis Reservoir Test Sites (Figure 3 and 4, respectively) despite differences in the amount of forage produced and the length of the green feed period. For example, at both Test Sites the outset of germination was indicated when radiances from all four bands are very nearly the same, and from which point the infrared bands increase while the visible bands decrease in radiance value. Notice this separation point occurs in mid-October for the Pinole Site, but does not occur until early November for the San Luis Reservoir Site. (This is consistent with the ground observations.) The radiance curves for the infrared bands peak in mid-April at Pinole and prior to early April at San Luis Reservoir Site. These peaks coincide with the time when the annuals were at their peak green stage and when green forage production was near maximum. Radiance values from bands 4 and 5 cross over in mid-May at Pinole and mid-April at San Luis Reservoir Site. These crossovers coincide with the period when half of the forage was dry at each site, respectively.

The conclusion to be drawn from these curves is that LANDSAT radiance data appears to provide a quantitative measure of the time of germination, the time of peak greenness or near maximum forage production, time when half of the forage is dry, and the time when drying is complete. This information permits determination of the length of various growth stages throughout the life cycle of the annual forage plants. The LANDSAT spectral data correctly revealed that annual plants germinated later, and matured and dried earlier at San Luis Reservoir compared to similar plants at Pinole.

LANDSAT radiance data from band 7 and 5 were formed into a ratio (7 over 5), and plotted over time (the dates of acquired cloud free LANDSAT data). The radiance ratio curves for both Pinole and San Luis Reservoir are plotted in Figure 5. The curves reach a low point at or before germination. The ratio curves peak during the spring coinciding with the occurrence of peak foliage production. Thereafter, the curves fall signaling the period of drying following the maximum green period. Once the curves level off, one can conclude that all annual vegetation has dried.

The LANDSAT radiance ratio curve for Pinole is an integration of reflected radiance from bottomland, midslope and upland sites which are contained within the 36 picture element study area. This curve compares favorably in shape with the ground reflectance ratio curves for each range site seen in Figure 2, if one disregards the high reflectance ratios measured on the ground early in the growth season.

When the LANDSAT radiance ratio curve for Pinole is compared with the one for San Luis Reservoir (Figure 5), one can observe the difference in timing of critical growth stages. Moreover, the difference in magnitude for these two curves corresponds to the relative difference in forage production at the two range sites. Thus, the LANDSAT radiance ratios appear to provide a valid quantitative method for comparing relative differences in forage production for different grazing regions throughout the annual grassland, as well as assessing the timing of growth stages and determining range condition (greenness or dryness).

DISCUSSION

MONITORING GROWTH STAGES AND CONDITION OF ANNUAL FORAGE

Although a complete sequence of cloud free LANDSAT images was not obtained, coverage at the critical growth periods was available for the San Francisco Bay Area frame to demonstrate that the time of growth events, the stage of plant development, and the condition of the annual forage can be determined from mannual interpretation of LANSAT IMAGERY. The critical stages which must be monitored, in order to assess the relative length of the green feed period, to assess relative productivity and forage quality, and to determine the availability of green forage, are the period of germination, the peak of the green foliage production stage, and the period of drying. If LANDSAT coverage is not available or of unusable quality due to cloud coverage, then supplemental data would be required. This could be in the form of ground reconnaissance or aerial reconnaissance from a light aircraft. If, however, supplemental data is required for more than one of the three critical growth stages, the efficiency gained from interpreting LANDSAT imagery decreases.

Whereas manual interpretation of LANDSAT imagery appears to be sufficient for identifying forage growth stage and condition, the element of interpreter subjectivity is inherent in the analysis of the images. Interpreter subjectivity by itself is not sufficient reason to discount the potential beneficial applications for using repetitive satellites to monitor changes in the condition of the California annual grassland, but an operational system which proposes to not only determine range conditions but provide predictions of forage production and extended length of the green feed period, of necessity requires more quantitative methods. Consistent with this need, the results from analysis of ground reflectance measurements coupled with analysis of LANDSAT spectral radiance data indicate that changes in spectral reflectance characteristics of the annual grassland provide the quantitative indicators of plant growth stage and range condition. Specifically, the spectral radiance data from the LANDSAT MSS bands, and ratios of selected bands appear to provide accurate indicators of germination, peak of green foliage development, and the drying period. Moreover, the shape and magnitude of these reflectance data curves plotted over time provide a measure of the relative difference in condition and production and a measure of the differences in timing of growth stages between sites or grazing regions. To the extent that LANDSAT data is available at similar dates in different growing seasons, one can determine differences in time of grow stage and productivity between years. This may be as important an application of LANDSA data as monitoring differences in development of the different grazing regions within a single season.

The criteria required for an operational monitoring system would include: (1) cloud free LANDSAT tapes (corrected for atmospheric differences) from representative Test Sites or ANALOGOUS alternative sites during critical growth periods which will occur at different and unpredictable times at the different grazing regions within the state; (2) less than one week turn-around time for receipt of tapes during the peak of foliage development and the drying period; (3) backlog of phenology and production data upon which to make predictions of remaining length of green feed period, and regression equations for relating LANDSAT spectral reflectance (radiance) values to estimates of forage production; and (4) a medium for disseminating data to potential users. The LANDSAT system is vital in acquiring the data base required for the surveillance of the annual grassland for the following reasons: The annual grassland encompasses a large area (approximately 8-10 million hectares); the range of annual grasslands in the state encompasses many different environments from the 12 cm. rainfall zone to the 100 cm. rainfall zone, from sealevel to 1000 METERS, and a wide temperature range throughout approximately 8 degrees of latitude; the repetitive coverage over the same areas, the use of scanner data and transmission equipment shows different range areas under the same lighting making comparisons of sites valid.

DETERMINING RELATIVE AMOUNT OF FORAGE WITHIN AND BETWEEN SEASONS

Estimating or predicting the amount of forage produced within a given grazing region for a given year is a difficult yet important task for managers of forage resources. Conventional methods are generally inadequate or unrepresentative of large areas to provide a valid assessment of the quantity of forage produced within and between seasons. However, the feasibility of using remote sensing data to estimate or predict forage BIOMASS is demonstrated both in the literature (Tucker, Miller, and Pearson, 1973; Rouse, 1973; Maxwell and Johnson, 1974) and by the relationships discussed in this study. Namely, that relative differences in forage production for different sites in the same area (Pinole) correspond closely to difference in measured ground spectral radiance from the forage at these sites. Moreover, relative differences in forage production at two different grazing regions (viz. Pinole and San Luis Reservoir) are expressed in this study by measured differences in LANDSAT spectral radiance data extracted directly from the LANDSAT tapes. What is common to these methods for assessing forage production is the apparent high correlation between SPECTRAL REFLECTRAL RATIOS in specific bands (viz. the red and near infrared bands) and green forage biomass. Deviations from this relationship were noted early in the growth season when high reflectance values were explained by active plant metabolism and by MORPHOLOGICAL characteristics of the plants during an early stage of growth. Although atmospheric haze was not a problem in this study, it is not known to what extent atmospheric conditions could invalidate the close relationship between biomass and reflectance characteristics.

Although the feasibility of assessing relative differences in forage production within and between sites is encouraging, range managers still seek reliable data regarding the estimated amount of standing biomass. Such estimates can be obtained using regression equations which regress LANDSAT spectral radiance data with ground sampled forage production data. Further study is needed in the area of ground sampling required to provide valid forage production data to be compared with the LANDSAT spectral data. The problem is that a single LANDSAT picture element or a group of LANDSAT picture elements may integrate many range sites with varying amounts of forage production. Thus, it is important to obtain ground samples in such a manner as to determine average forage production associated with a single or group of picture elements.

A second approach to estimating forage production using direct inputs from LANDSAT imagery is based upon prior knowledge of the average forage produced (in a given area) associated with an average growth cycle. Here, departures from the normal growth cycle as expressed by the length of the green growth period and by the condition of the forage, combined with measured departures of LANDSAT SPECTRAL REFLECTANCE DATA provide the indicators of below or above normal forage production. Whereas, assessment of below or above normal conditions favorable for below or above normal forage production is still qualitative, the use of regression models (simple or multiple regression) which incorporate LANDSAT spectral reflectance data, ground data and climatic data where appropriate, enables more quantitative predictions of forage production to be made. Within a growth season, some grazing regions may experience above normal or below normal conditions for growth. Provided that the normal conditions are known for each of these grazing regions, one can determine relative differences in production between grazing regions for a given season. Similarly, when the average conditions are known for a given grazing region, departures from this average can be monitored using LANDSAT data and differences in forage production between seasons determined quantitatively. The extent to which assessment of length of green growth cycle and forage production can be made efficiently for large grazing areas depends upon the availability of LANDSAT data obtained at critical periods during the growth cycle. To determine the length of the growth cycle which is one variable closely associated with the amount of forage produced, one must acquire cloud free coverage during the germination period and the maturation and drying period at the end of the cycle. In order to assess differences in amount of forage through analysis of LANDSAT spectral data, the LANDSAT data must be acquired at the peak of the green forage production stage. Differential drying of plants after this period, causes radiance ratio values to decline although there may continue to be a small increase in total forage produced.

LANDSAT IMAGERY AS A MEANS FOR LOCATING AVAILABLE FORAGE

In Color Plate I the greenness or dryness of the forage can be determined visually upon inspection of the LANDSAT images. Moreover, the location of the areas possessing green forage during the latter portions of the growth cycle can be readily determined. Since this may vary from year to year, the LANDSAT monitoring system provides a potentially valuable tool for determining areas which either have abundant green forage due to favorable amount and distribution of rainfall, or areas which have dry forage relatively early in the growth cycle due to unseasonably low rainfall.

Because the LANDSAT spectral radiance response curves (Figures 3 and 4) indicate changes in the condition (greenness or dryness) and phenology of the forage, a quantitative approach to determination of forage condition and location is made possible. Furthermore, because of the distinctive spectral radiance differences between green and dry forage, automatic classification is a feasible and accurate method for determining the location and the area of range land which contains green healthy forage.

SUMMARY AND CONCLUSIONS

In this feasibility study LANDSAT imagery and magnetic tapes were analyzed to determine their utility for monitoring and assessing range condition within the annual grassland in California. LANDSAT data, forage samples at selected range sites, and ground spectral reflectance data were all examined in order to verify the usefulness of LANDSAT imagery for determining range condition, growth stage and assessing relative forage production. The results of GROUND SPECTRAL REFLECTANCE DATA compared with green forage production data show a close correspondence between spectral reflectance ratios and green biomass. Changes in ground spectral reflectance data also correspond with observed changes in growth stage and condition of the forage species. Moreover, LANDSAT spectral reflectance data provides quantitative signals of significant growth stages in the development of annual forage species. Relative differences in forage production are also indicated by the LANDSAT spectral radiance data.

It has been illustrated that LANDSAT color composite images provide a visual picture of the condition of the rangeland. Repetitive sequences of these images provide the means for monitoring change in condition and comparison of condition of different range areas. When LANDSAT spectral radiance data is extracted from specific range sites, one can determine quantitatively the occurrence of germination, the peak of foliage production, and the period of drying from spectral curves constructed from a sequence of LANDSAT images. In addition, ratios of spectral bands, namely 7 and 5, provide a sensitive indicator of changes in growth stages and an indication of the relative differences in forage production when two or more range areas are compared.

Provided that cloud free LANDSAT coverage is available during critical growth stages of the annual plants, namely, germination, peak of foliage production and period of maturation and drying, LANDSAT data can be used to: (a) assess differences in range condition on a regional basis; (b) compare differences in production between grazing regions for a given year; and (c) compare differences in condition and production for a given site between years. Moreover, the length of the green feed period can be determined and this information along with ground samples of forage production and climatic data can provide the inputs to simple models for estimating forage production or determining the remaining length of the green feed period beyond a definable threshold date late in the growth cycle of the annuals.

The anticipated benefits from LANDSAT monitoring of annual range vegetation include: (1) more accurate determination of germination and drying periods for planning movement of grazing animals to or from annual grassland ranges; (2) predictions of the remaining length of the green feed period made early enough to plan more efficiently for alternative sources of livestock feed; (3) comparison of conditions and relative forage production between grazing areas within a season, and comparison of condition and productivity for a given area between seasons; (4) determination of time when dry forage creates a fire hazard in order to better allocate men and equipment for fire suppression; and (5) assess extent and location of grazing areas influenced by abnormal climatic conditions, be it drought or abundance of forage.

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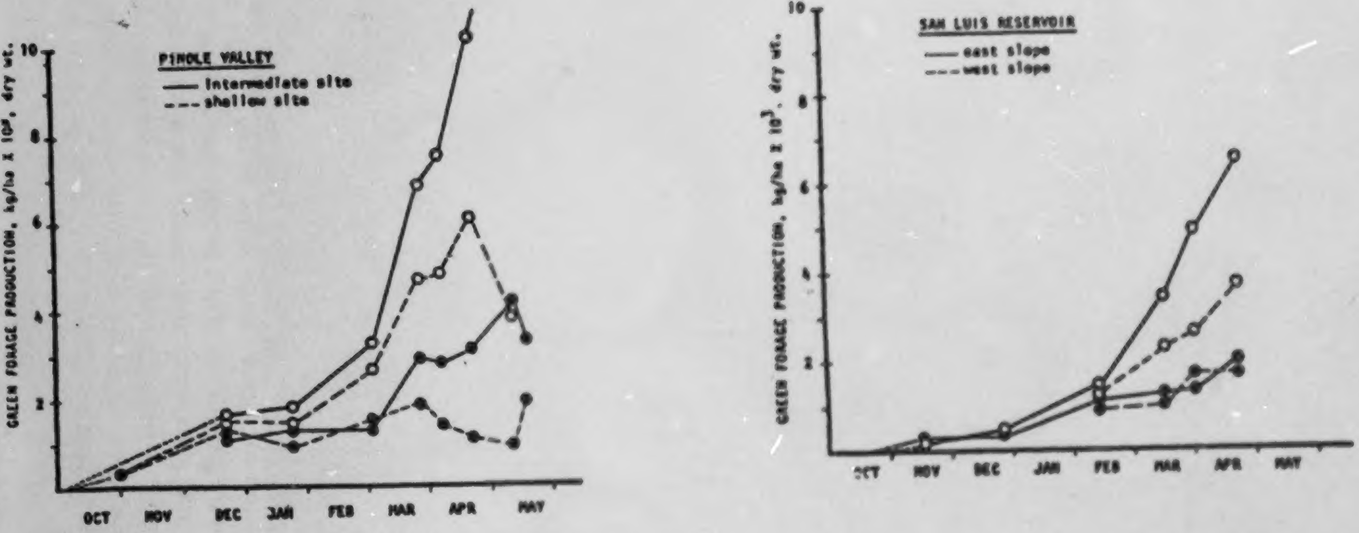


Figure 1. Total forage production, exclusive of residual material (over dry weight) at two of three sample sites at Pinole and at two sample sites near San Luis Reservoir. Samples were collected during the 1972-73 grazing season. Those made from ungrazed plots are indicated by an open circle. Note that forage production at Pinole is nearly double the production at San Luis Reservoir Test Site.

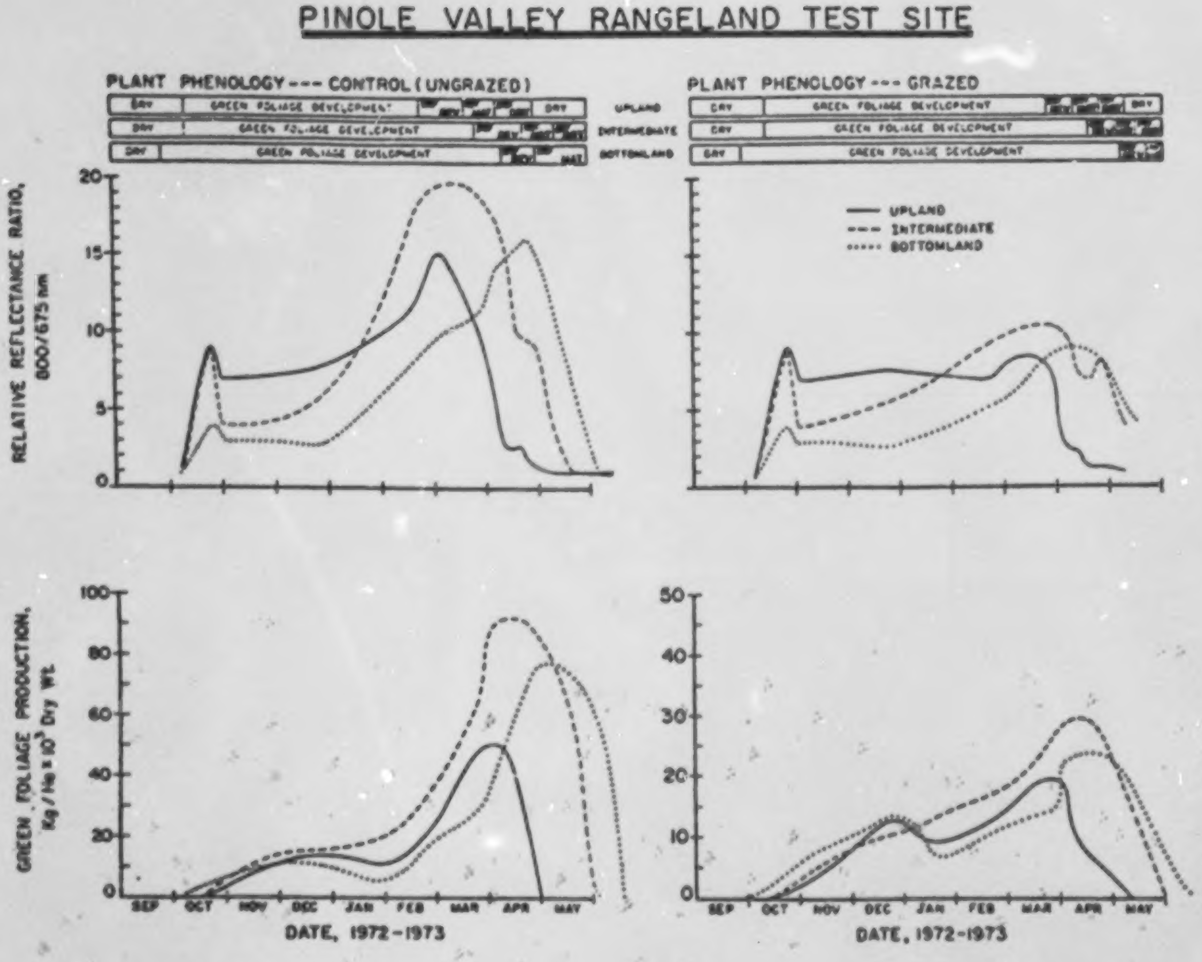


Figure 2. Green forage production and spectral reflectance ratio curves are plotted, and plant phenology is documented over time for three range sites at the Pinole Test Site. Note the correspondence of the shape of the curves (both production and reflectance) to changes in plant phenology as the annual grassland progresses toward maturity and subsequent drying. This correspondence is evident in both the grazed and ungrazed portions of the range sites. The phenological stages observed and documented include dry, green foliage development, inflorescence development (INF DEV), inflorescence mature (INF MAT), inflorescence dry (INF DRY) and dry.

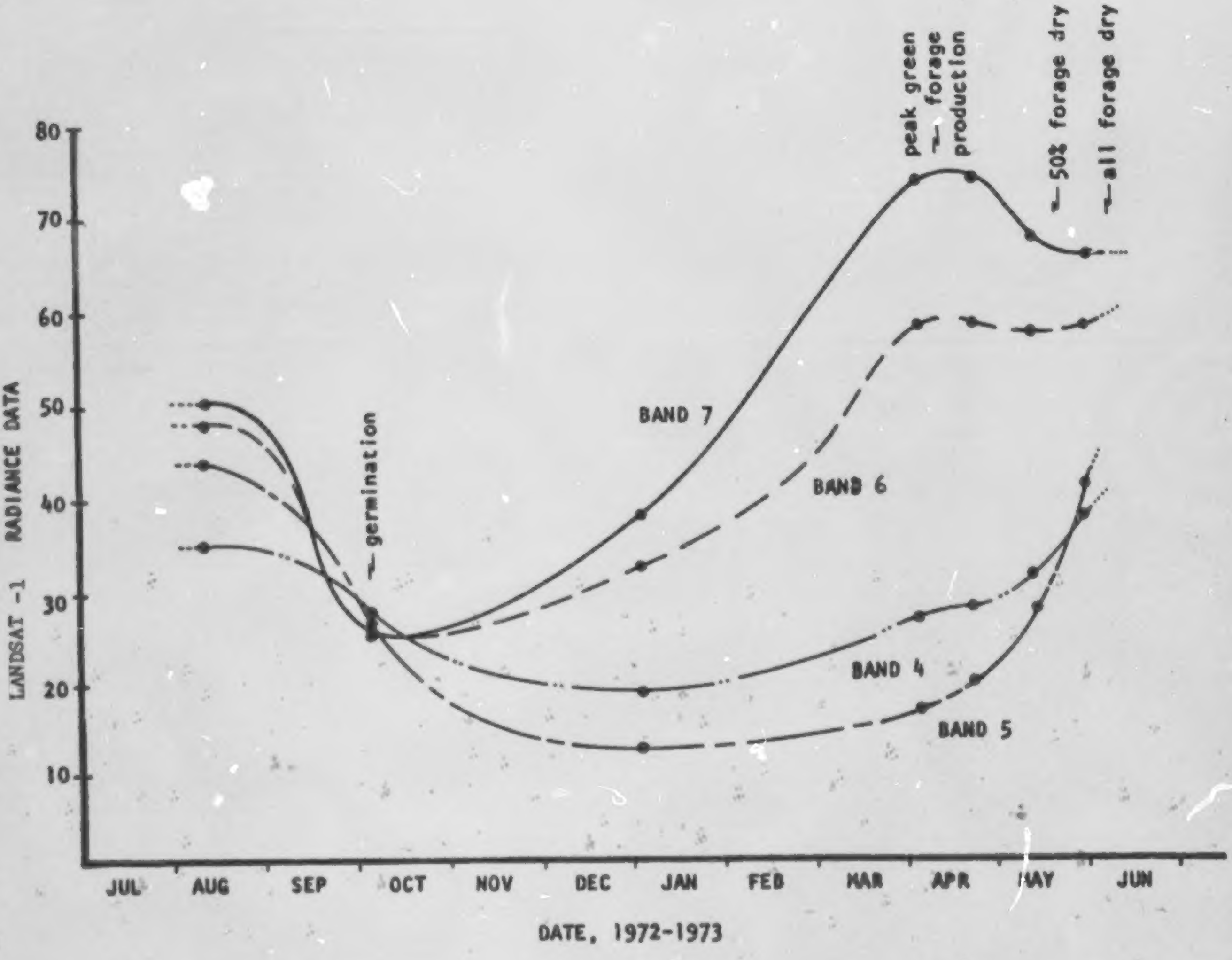


Figure 3. LANDSAT spectral reflectance curves for each MSS band (4, 5, 6, 7) plotted over time for the Pinole Test Site. The data used in this graph was extracted from LANDSAT-1 tapes for a 6 x 6 picture element area which includes the study sites where ground data was collected. Note how changes in the curves correspond with phenological stages of plant growth.

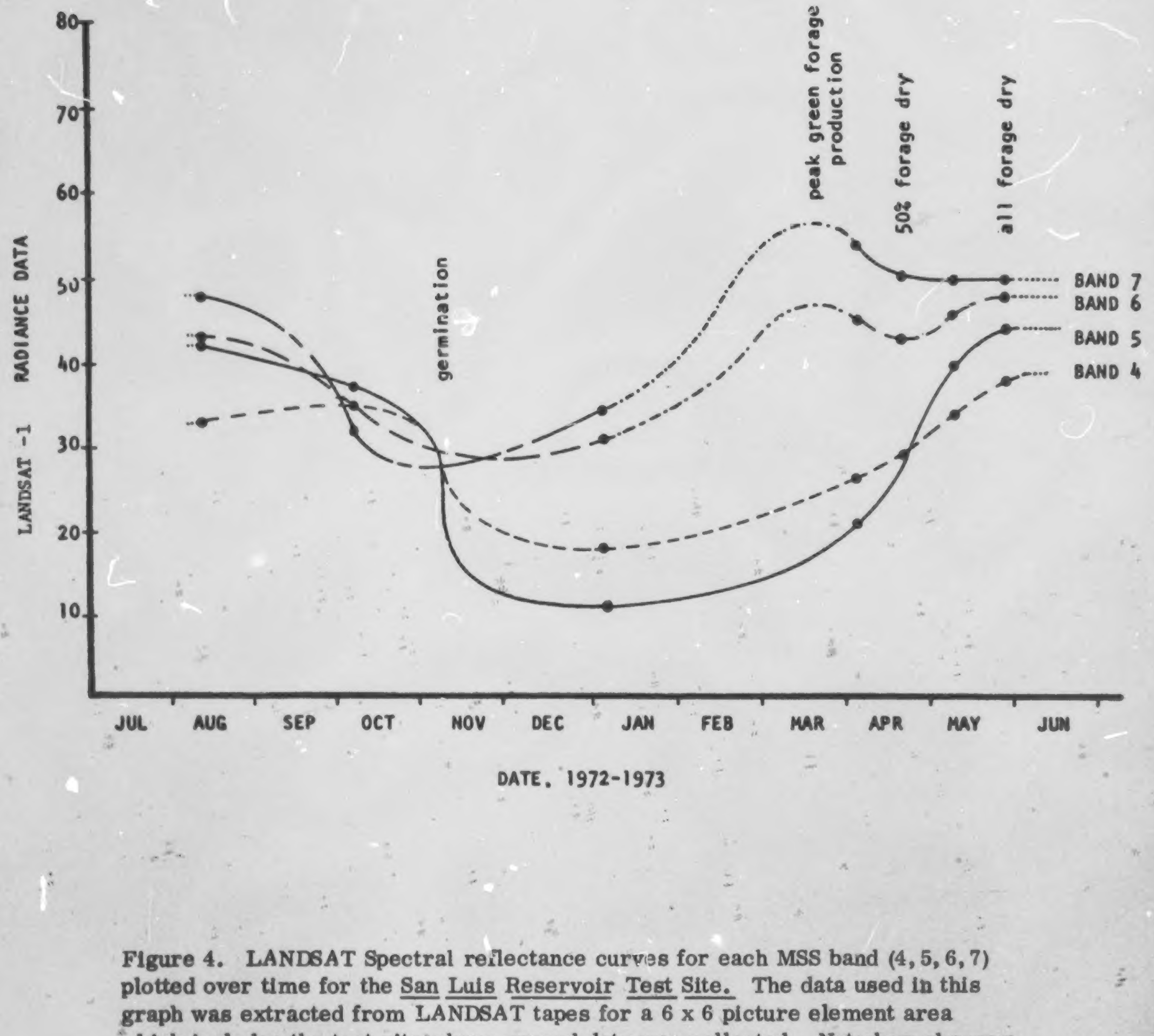


Figure 4. LANDSAT Spectral reflectance curves for each MSS band (4, 5, 6, 7) plotted over time for the San Luis Reservoir Test Site. The data used in this graph was extracted from LANDSAT tapes for a 6 x 6 picture element area which includes the test site where ground data was collected. Note how changes in the curves correspond with phenological stages of plant growth.

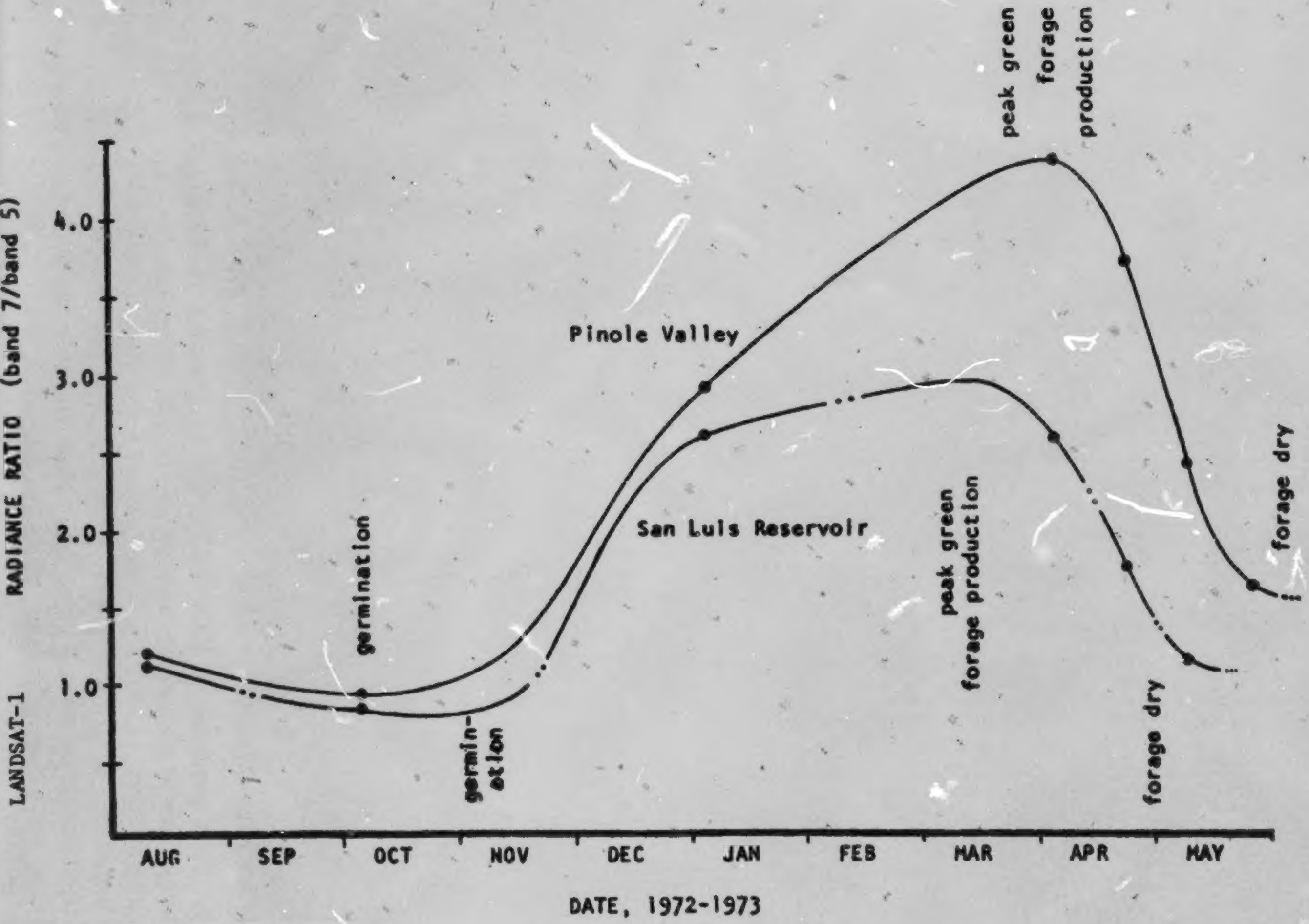
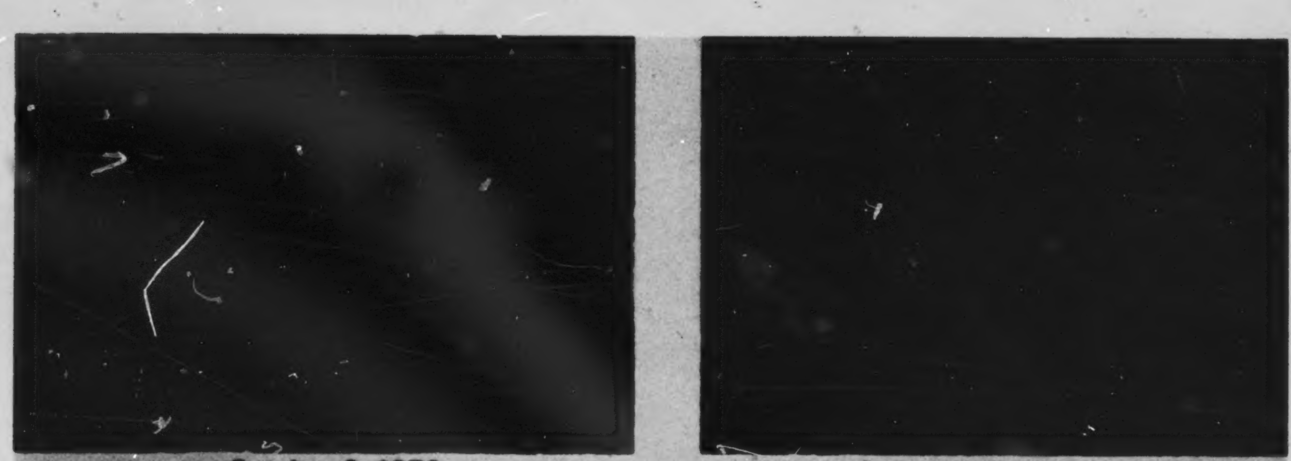
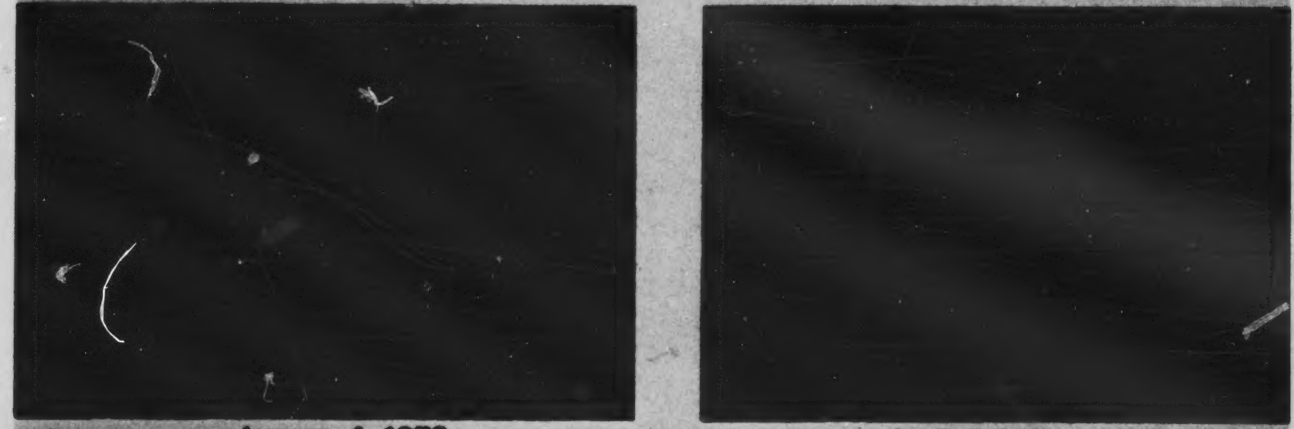


Figure 5. LANDSAT spectral reflectance ratio curves for the Pinole and San Luis Reservoir Test Sites. The ratio (band 7/band 5) is plotted over time for the 1972-73 grazing season. Note how changes in the curves correspond to the time of occurrence of phenological stages of plant growth. Difference in magnitude of the curves suggest the relative difference in forage production between the two sites.



October 6, 1972

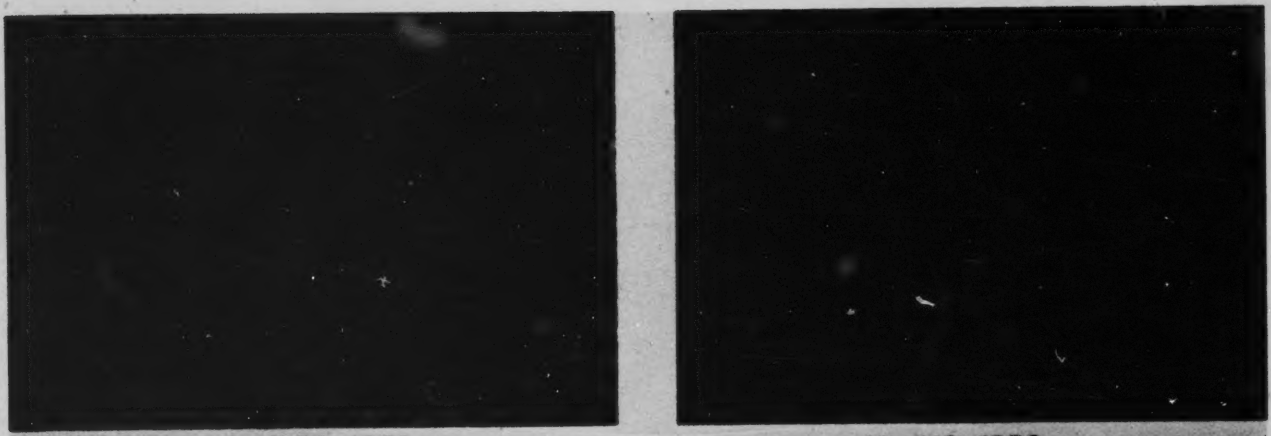
October 24, 1972



January 4, 1973

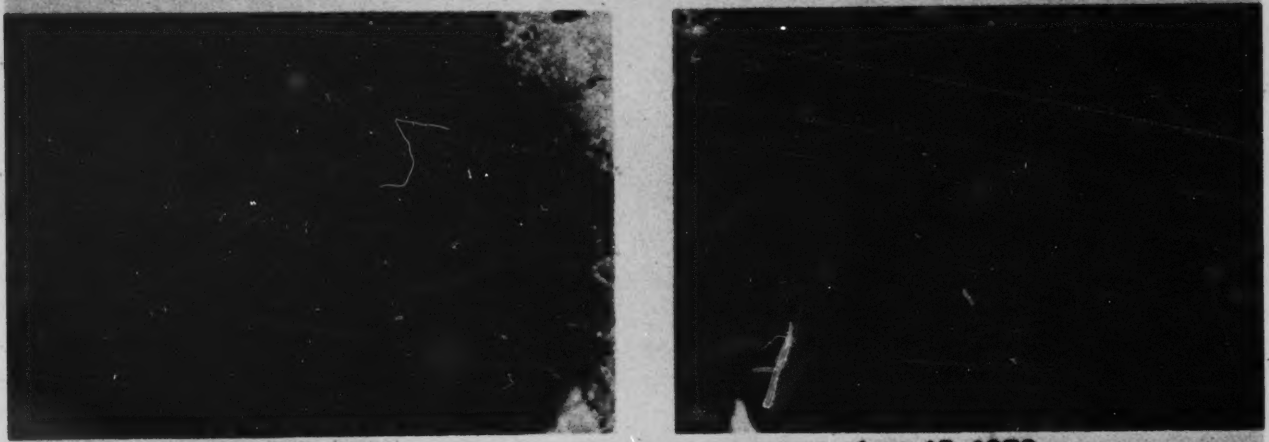
April 4, 1973

COLOR PLATE I. This sequence of LANDSAT color composites shows the changing appearance of the California annual grassland adjacent to the San Francisco Bay Area. The Pinole Test Site is located northeast of San Francisco, across the Bay and beyond the metropolitan area of the East Bay cities of Oakland, Berkeley and Richmond. The annual grasslands are readily identified on the October 6 color composite by their tan to gray color which indicate that the rangelands are still dry. Note that on subsequent dates germination and progressive plant growth account for the shift from tan to pink colors corresponding to the presence and vigor of the green annual plants. These rangelands reach a stage on April 4, 1973 where foliage production is near maximum, hence the bright red color seen on the LANDSAT color composite. Progressive drying beyond April 4 account for the shift in colors from bright red to orange to yellow. The ground photographs seen in COLOR PLATE II show how the annual rangeland appeared on the dates of the LANDSAT overpasses.



April 22, 1973

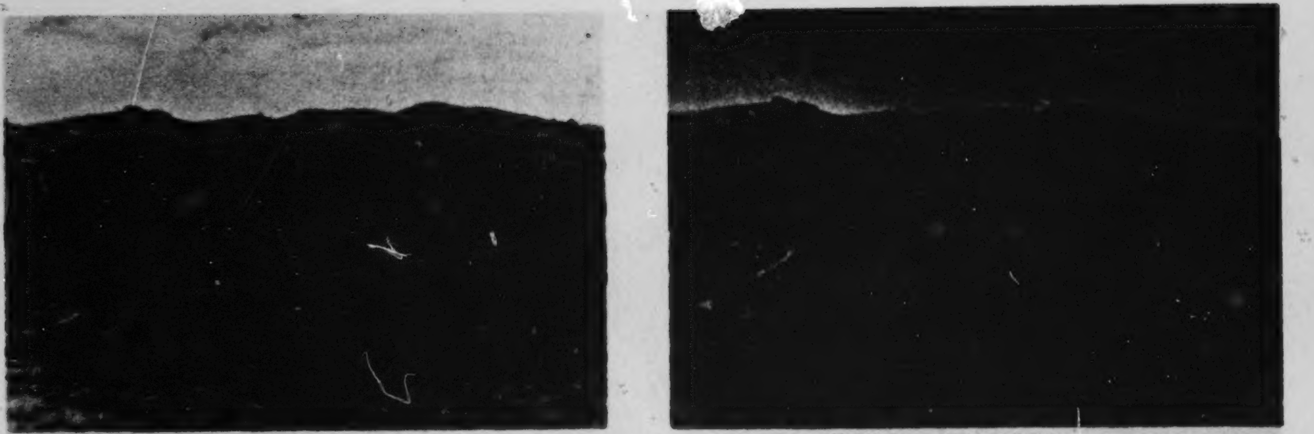
May 10, 1973



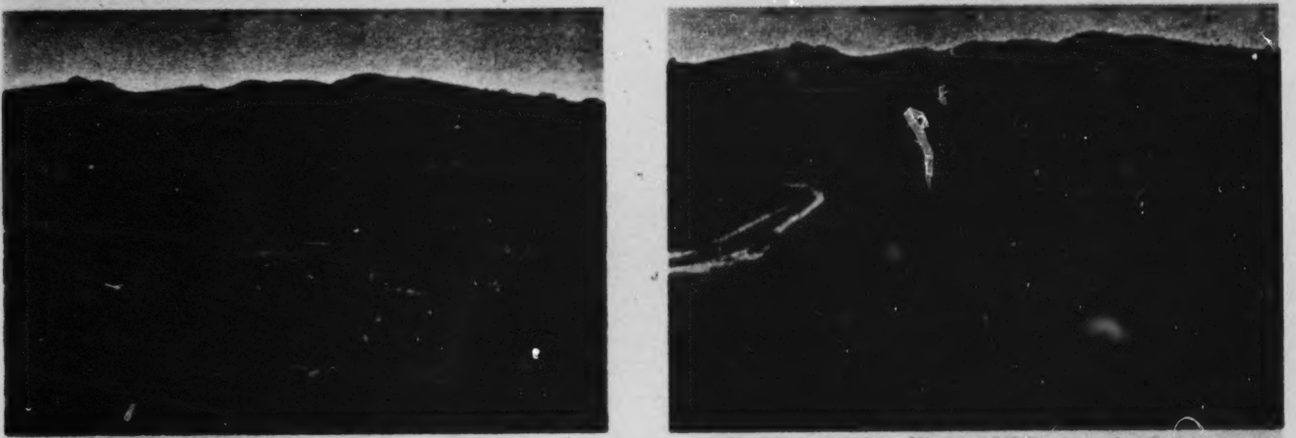
May 28, 1973

June 15, 1973

COLOR PLATE I. CONCLUDED.

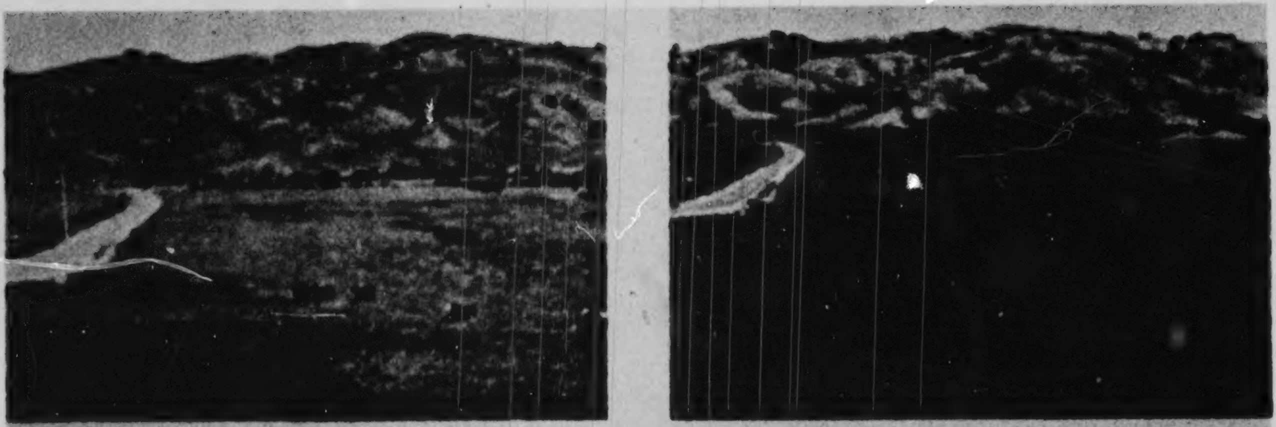


October 6, 1972 **October 24, 1972**



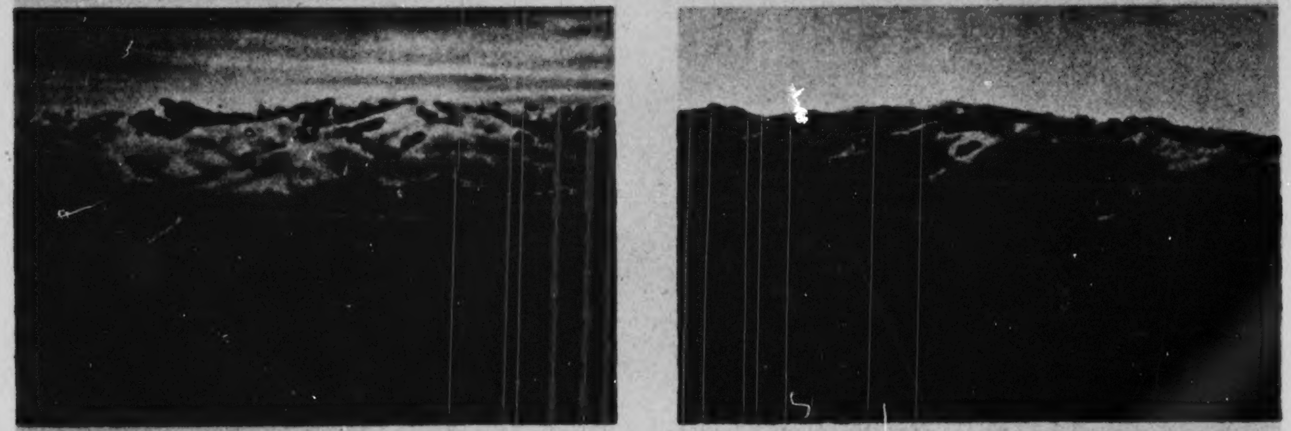
January 4, 1973 **April 4, 1973**

COLOR PLATE II. This sequence of eight ground photographs shows the changing appearance of the annual grassland range at the Pinole Test Site during the 1972-73 growing period. The dates of the ground photographs coincide with the date of LANDSAT overpasses. The LANDSAT color composite images for the corresponding dates are seen in COLOR PLATE I. Note that germination of the annuals has occurred between October 6 and October 24, 1972. Note also that on April 4, 1973, the rangeland still appears green, but progressive drying of the forage plants is evident on subsequent ground photographs. In early April the forage plants had reached their peak for foliage production and were rapidly developing in florescence and maturing.



April 22, 1973

May 10, 1973



May 28, 1973

June 15, 1973

COLOR PLATE II. CONCLUDED.

PINOLE TEST SITE
SAN LUIS RESERVOIR

COLOR PLATE III. This LANDSAT-2 color composite of the San Francisco Bay Area shows the location of the Pinole and San Luis Reservoir test sites discussed in this paper. This image was taken on January 24, 1975, and provides an opportunity to compare range conditions in January 1975 with conditions in January 1973 (Color Plate I). The relatively brighter pink color associated with the annual grasslands as seen on the January 4, 1973 LANDSAT-1 image correctly indicates that plant growth and forage production in January 1973 exceeded that in January 1975. Range conditions in January 1973 were normal or slightly in excess of normal, whereas in January 1975 range conditions were considerably below normal causing ranchers to reduce stocking rates and provide feed supplements to sustain their grazing animals.

CALIFORNIA GRASSLAND

Vocabulary - Define the following terms in detail.

- Rangelands
- LANDSAT
- Growth cycle
- cm
- Hectares
- Geomorphology
- Physiography
- Climatic regime
- Germination
- nm
- Color infrared
- Rainfall zone
- Medicago hispida
- Trifolium microcephalum
- Festuca megalura
- Hordeum
- Lolium multiflorum
- Bromus mollis
- Erodium botrys
- Bromus rigidus
- Spectral reflectance ratios
- Phenelogical

Questions - Answer the following inquires in detail.

1. What benefits were obtained via LANDSAT monitoring of the annual range vegetation?
2. Discuss the estimation techniques of obtaining the average growth cycle using direct inputs from LANDSAT imagery.
3. What were the objectives of this research project?
4. Discuss the differences in forage producing areas.
5. What parameters affect the green growth period?
6. What were the range conditions during the 1972-73 growth period?
7. Explain the methods used in collecting ground data.
8. How are reflectance ratios formed?
9. Why are cloud free days important in obtaining imagery?
10. What effect did the storms have on the Pinole Test Site?

Discussion Topics

1. What hydrological conditions must exist for good range conditions?
2. Explain the inter-relationship between flora and fauna as it relates to the grasslands.

UTILIZATION OF LANDSAT IMAGERY FOR MAPPING VEGETATION ON THE MILLIONTH SCALE

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ABSTRACT

The United Nations Educational, Scientific and Cultural Organization (Unesco) has recently published a vegetation classification system. This system, based on the physiognomy of the vegetation, is designed to provide a comprehensive framework for the preparation of vegetation maps of any part of the world at scales of 1:1,000,000 or less. The utility of the system lies in the fact that optimal agricultural land uses are always related to the natural vegetation.

The system is designed for use with maps covering large areas. The large map area, however, poses a severe problem in uniform data collection, especially if large-scale imagery is employed as a mapping base. Since LANDSAT images have a basic utilization scale of 1:1,000,000, identical to that of the projected maps, they would serve as a uniform base for all parts of the world if they contained the information necessary to delimit vegetation formations.

To determine if the information content of the imagery is sufficient to permit mapping according to the Unesco classification, a series of test sites have been examined. These sites include examples from the humid tropics, arid and semi-arid subtropics and temperate zones. In every case the feasibility of this application of LANDSAT imagery has been verified. The agricultural significance of several sites is discussed to indicate how the vegetation maps may be interpreted for agricultural evaluation.

INTRODUCTION

In 1965 the Standing Committee on Classification and Mapping of Vegetation of the United Nations Educational, Scientific and Cultural Organization (Unesco) began consideration of a classification of vegetation. The Committee, composed of authorities from throughout the world, worked through the next decade to develop its classification. As published in its final form (ref. 1), this classification system is designed to provide a comprehensive framework for the preparation of vegetation maps of any part of the world at scales of 1:1,000,000 or less. Utilization of the system would result in the production of maps providing a solid basis for comparison of vegetation in all parts of the world.

The utility of such a system lies in the fact that optimal agricultural land uses are always related to the natural vegetation. Consequently, if successful production of a certain crop occurs in areas where ecological conditions produce a particular vegetation type, other parts of the world possessing the same vegetation type and, therefore, the same environment, will also be suited to the cultivation of that crop. As human populations continue to grow, it becomes ever more necessary to produce those crops best suited to each part of the Earth's surface to ensure the optimum availability of food and other agricultural commodities. This classification is therefore particularly relevant to large-area planning problems.

Prior to final publication of the system, field trials were conducted in Costa Rica by Küchler and Montoya Maquin (ref. 2). These trials established the feasibility of field classification of vegetation units under the system. Subsequently, Williams, et al. (ref. 3) mapped a small area in northeastern Kansas. Although the map was published at a large scale (1:12,000), the feasibility of using the system was once again demonstrated. To date, no small scale map based on the Unesco classification has been published. Nevertheless, these results clearly indicate that the system is usable.

The classification is based upon PHYSIOGNOMIC rather than FLORISTIC criteria. Physiognomy refers to the physical appearance or growth form of the vegetation while the floristic composition is the list of plant species which are present in a plant community. Although interconnected, physiognomy and flora are not identical. Thus, a given group of plant species may exhibit different physiognomies under different environmental conditions. For example, trees which form dense forests at lower elevations become reduced in size and tree density decreases near timberline. This changes the physiognomy of the vegetation from closed forests to open shrublands although the principal species are the same. On the other hand, different groups of plant species may exhibit identical physiognomies when growing under similar environmental conditions. This phenomenon has long been recognized in the wintergreen shrublands of California, the Mediterranean basin, southern Australia, South Africa, and Chile where the plants respond to the concentration of precipitation in the cool season. Because the Unesco classification is based upon physiognomy, it results in all such shrublands being assigned to a common class, accurately reflecting the comparability of environments in these areas (ref. 4).

The Unesco classification is an open-ended hierarchy with the formation as the basic unit of the system. As illustrated below, three levels exist above the formation. Although the definition is amplified in the text of the classification, the formation name is sufficient to inform the map reader that this example vegetation type is a forest, with tree crowns touching, composed of trees which are (1) broadleaved; (2) evergreen; (3) grow in warm, very humid areas; and (4) are in permanently inundated localities. In preparing the classification the Committee designated some subformations, but the individual is free to add other subformations or further subdivisions and to augment the formation name with floristic data or significant local names of the vegetation type. The mapper might thus specify that his formation is locally known as chaparral in California and macchia in Italy.

Classification Unit	Example
Formation Class	Closed Forest
Formation Subclass	Mainly evergreen forest
Formation Group	Tropical ambrophilous forest
Formation	Tropical ambrophilous swamp forest

Five formation classes have been designated by the Committee, encompassing all terrestrial and emergent aquatic vegetation known to occur. These formation classes are defined in the following manner (ref. 1).

Formation Class	Definition
Closed forest	Formed by trees at least 5 m tall with their crowns interlocking
Woodland	Composed of trees at least 5 m tall with crowns not usually touching but with a coverage of at least 40 percent.
Scrub	Mainly composed of woody plants 0.5 to 5 m tall.
Dwarf-scrub	Composed mainly of woody plants rarely exceeding 50 cm in height.
Herbaceous	Dominated by an herbaceous synusia and with woody plants not covering more than 40 percent of the area.

Systems of subdivision used in each formation class are consistent within limits imposed by the characteristics of different plant growth forms and the range of naturally occurring vegetation types.

Cultural vegetation is treated as a separate and unique portion of the vegetation. Units of natural vegetation are used to infer ecologic conditions in cultivated and urbanized areas but such predicted areas are always distinctively indicated on the map.

SMALL-SCALE MAPPING METHODS

As detailed by Küchler (ref. 6), two basic methods exist for preparing small-scale vegetation maps. One of these methods is compilation. In compilation, all of the previously published vegetation maps of the study area are collected, common legend elements are extracted for a composite legend and the maps are compiled onto a common base. This method is feasible only if large- and medium-scale maps have previously been produced for the entire study area. Even then, substantial difficulties may arise because some maps may show floristic, others physiognomic, and still others ecologic classes and these legends may prove irreconcilable.

The second method of generating small scale vegetation maps is primary mapping. The principal components of this method are (1) acquisition of a set of aerial photographs, (2) delineation of vegetational boundaries apparent on these photos, and (3) a field survey to verify the boundaries and identify the vegetation units enclosed by these boundaries. In general, the products of primary mapping methods are considerably superior to products of compilation methods because of consistency of the legend classes.

Considering that the objective of the Unesco vegetation classification is to provide a basis for small-scale mapping and that the objective of small-scale maps is large-area coverage, primary mapping methods pose a serious problem. Areas suitable for inclusion on a single map sheet at the millionth scale may well be of the order of size of the state of Kansas, over 200,000 km^2. Over such an area, large scale imagery of uniform quality, scale, and date is rarely available. Even if such imagery were available, utilization poses a severe handling problem. Since each frame of 1:20,000 aerial photography represents a gain of approximately 5 km^2, about 40,000 frames of 9-inch format photography are required to cover the state. Nor is the standardly available imagery time-synchronous. In fact, the most current available set of photos for the state of Kansas have acquisition dates spanning a period of 16 years. The dollar cost and physical problems attendant on acquisition of a new set of images for such an area eliminate a special mission as a viable alternative. Since the actual surface area represented by the gain of one 1:20,000-scale photo will be portrayed by only 5 mm^2 on the finished map, most of the detail evident in the photo will have to be discarded during reduction. Acquisition of surface observations about all of the boundaries and types evident on the photo will represent large expenditures of wasted field effort. Further, the sheer mechanics of a 50 X scale reduction are costly and fraught with error potential.

In contrast to the problems of large-scale imagery specified above, LANDSAT images have a basic utilization scale of 1:1,000,000, identical to that of the projected maps. This scale effectively eliminates problems associated with reduction of the manuscript map and facilities use of optimum current CARTOGRAPHIC techniques. Parts of only 18 scenes are required to cover the state of Kansas, eliminating the aforementioned image handling problem. Although resolution is sufficient to record more detail than can be reasonably reproduced on the finished map, unnecessary detail has already been generalized out of the image by the acquisition process. The imagery provides a uniform mapping base for all parts of the world, thereby solving the difficulties of procuring a suitable base map.

Since it is evident that LANDSAT imagery would prove useful for vegetation mapping at the millionth scale, the remaining question must be whether the vegetational information contained in the images is that required for distinguishing formations as established in the Unesco classification.

MATERIALS AND METHODS

In order to test the feasibility of using LANDSAT MULTISPECTRAL SCANNER (MSS) imagery for vegetation mapping, a series of test sites was selected. These sites represent a wide range of physiognomic types, although they do not include every formation in the classification. Each test site was chosen on the basis of available MSS images and supporting data in either the form of direct observations by the authors or published maps and analyses of the vegetation amenable to use in the Unesco classification. The sites illustrated in this discussion are indicated on Figure 1, which also indicates several supplementary sites checked in the course of the investigation.

Color composite LANDSAT images were employed for interpretation of vegetation boundaries and the formations were determined by comparison with the supporting data. In addition, consideration was given to the image characteristics associated with each of the formations.

RESULTS

Results of this experiment are presented in the form of vegetation maps and annotated images which will serve to illustrate the detectability of various formations. The range of problems and potentials associated with small-scale vegetation mapping are indicated by Figure 2, which presents a vegetation map of a portion of the Western Highlands of Papua New Guinea together with the LANDSAT MSS image from which it was prepared from bands 5 and 7 only. This was done because degradation of band 4 due to atmospheric scattering is extreme in very humid areas. Current experience indicates that loss of image sharpness (SPATIAL RESOLUTION) due to incorporation of band 4 more than offsets any gain attributable to spectral differences between bands 4 and 5, as long

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as targets such as natural vegetation are under consideration. Except for the Papua New Guinea scenes, however, all composites used in this study are conventional combinations of bands 4, 5, and 7.

The basic relationships between image and map are readily apparent (Figure 2). However, a number of details deserve comment. Although boundaries between formations are often sharp, they are not always so. Two examples of this condition are apparent in the present illustration. One is the boundary between the Tropical Ombrophilous Submontane and Montane Forests. In some areas this boundary is clearly evident on the image whereas in other areas it is diffuse. Such diffuse boundaries, collectively termed transitions, are quite common in natural vegetation. In the present case, where the change information is associated with altitudinal changes, it is not surprising that transitions occur in areas of moderate regional slope while relatively abrupt boundaries are characteristic of more precipitous slopes. That a transition is occurring in this area is evident by the gradual changes in color evident across the zone and the distinctness of the areas at opposite edges of the transition zone.

The second special boundary type is a mosaic such as that observed between the Tropical Ombrophilous Cloud Forest and Tropical Alpine Bunchgrass atop Mt. Giluwe. Here the two formations are physically discrete but are distributed in units of such a size that they cannot be shown as discrete mapping units. Rather, then, they are shown as mosaics of the formations of which the area's vegetation is composed.

The necessity for interpreting beyond color recognition is illustrated by comparison of sunlit and shadowed mountain slopes and of the two GRAMINACEOUS formations. In the first case, the color shift within one formation due to directness of illumination is of the same order as the color shift between formations under constant illumination. In the second case, although colors of the Tropical Grassland and the Tropical Alpine Bunchgrass are in some cases quite similar, topographic position readily establishes ecologic differences between these formations. In addition, it is quite evident from the case of the Tropical Grassland that subformational distinctions are possible. The pinker shades in this mapping unit are associated with vegetation composed of *Phragmites karka* (tall swamp reed) while the light blue sites are dominated by sedges and other grasses (ref. 6). In other cases, however, accuracy of subformational distinctions remain uncertain. Although the darker red areas within the Tropical Ombrophilous Montane Forest include all areas mapped by Saunders (ref. 7) in a class identifiable as the Microphyllous Subformation, substantial areas not mapped by Saunders exhibit identical image characteristics. Without further ground survey, a positive statement regarding the feasibility of subformation mapping in the forests of this region is not possible. On Mindoro Island, Philippines, however, the Needle-leaved Subformation of the Tropical Ombrophilous Submontane Forest is visually distinctive (ref. 8; Coiner, pers. obsv.).

As plotted on this map (Figure 2), cultivated land includes land under cultivation and those areas in various stages of regrowth. Since most agriculture in the highlands of Papua New Guinea occurs as shifting cultivation, a complex mixture of apparent vegetation types is to be expected and is, in fact, observed. Areas of cultivated land are classified according to their ecological zone. That is, the map color of each cultivated area reflects the apparent formation to which the area belongs. Distinctly different crops are cultivated depending upon the ecologic potential of the area.

In addition to shifting cultivation of subsistence crops, two crops are commercially important in the major highland valley in the northeastern part of the map area. These crops are coffee and Pyrethrum. Pyrethrum flowers yield a powerful contact insecticide now widely used in sprays. These crops are well-adapted to export and therefore desirable for cultivation in a developing region because of their capacity to generate foreign exchange.

The potential utility of preparing vegetation maps on the millionth scale is illustrated by comparison of Figure 2 with Figure 3A. The latter is a LANDSAT image of a valley lying further west in Papua New Guinea. Unlike the area included in Figure 2, no ground surveys of resources have yet been completed in this western valley. Comparison of the two scenes, however, demonstrate the general similarity of vegetation formations in the two valleys. The western valley should therefore prove suitable for further expansion of these agricultural industries.

Although striking similarities are evident, certain distinctive aspects of the vegetational formations on Mindoro Island, Philippines (Figure 3B) deserve comment. Unlike the Western Highlands of Papua New Guinea, where a sword grass (Miscanthus floridulus) regrowth predominates, extensive burning of forest on Mindoro has resulted in establishment of Imperata cylindrica (cogon, kunai) Tropical Grassland (Coiner, pers. obsv.). The lower elevations and coastal areas of Mindoro support two formations not evident at the higher elevations of the New Guinea sites, the Tropical Ombrophilous Lowland Forest and Mangrove Forest. Mangroves have proven visually unique on all images examined, irrespective of adjoining vegetation types.

Many forests include both deciduous and evergreen trees in varying proportions. Deciduocity may be associated with pronounced seasonality of either precipitation or temperature. Although color differences between the evergreen and deciduous Formation Subclasses are evident during the leaf season, distinctions ensuring recognition of the Formations are enhanced by selection of images which exhibit the deciduous forest in a non-leaf or partial leaf condition. The contrast between such images is amply illustrated by comparison of Figures 3C (12 July 1973) and 3D (15 October 1972). The Great Smoky Mountains of the southeastern United States have Evergreen Needle-leaved Forest with Conical Crowns at the highest elevations (ref. 9; Williams, pers. obsv.). This formation, dominated by spruce (Picea) and fir (Abies), retains the red color of living vegetation after deciduous leaf-fall has eliminated the red color of the Montane Cold-deciduous Forest, so designated to distinguish it from drought-deciduous forests, which replaces the Evergreen Forest at lower elevations. At still lower elevations, the deciduous forests are replaced by Cold-deciduous Broad-leaved Forest with Evergreen Needle-leaved Trees, with rounded crowns in this case. This mixed forest of deciduous and pine trees of the lower elevations of the Valley of East Tennessee has now been largely replaced by cropland and other human uses except in those localities too rugged for farming. In contrast, areas ecologically suited to the occurrence of deciduous forest in this region have remained forested because they are quite unsuited to cultivation due to topography and soils.

In sharp contrast to the heavily vegetated humid regions just examined, the vegetation of the interior of Western Australia (Figure 4A) is predominantly a Semideciduous Subdesert Shrubland. The mulga (Acacia aneura) and associated shrubs are facultatively deciduous. That is, they put out leaves whenever sufficient soil moisture is available to support growth and shed these leaves whenever the moisture supply drops below some minimum (ref. 10). This event may occur several times in a single year. At the time of image acquisition (30 November 1972), the shrubs were in leafless condition. Nevertheless, the shrublands are distinctive from the Medium-tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs, although the boundary between these formations is generally gradual because the only difference between the two formations is shrub density. As the breakaways of the highlands are approached, large areas are nealy barren. Despite the inactive status of the vegetation of most of this region, formational distinctions are, then, feasible.

Representing a condition intermediate between the dense vegetation of the humid and sparse vegetation of the arid areas previously examined, northeastern Uganda illustrates conditions prevailing in a tropical savanna (ref. 11). Moisture supply varies greatly in this area, resulting in a distinctive vegetation pattern. Tropical Grassland composed of Cyperus papyrus occupies the permanet swamps of the major stream valleys. On sites having impeded drainage but not being permanently swampy, the Tropical Grassland is replaced by a Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs. Much of the area covered by this vegetation type is subjected to frequent burning, as is readily evident on this image. Because of the heavy-textured soils under this formation, which cause the drainage to be impeded, the area is not suited to cultivation and is used only for grazing cattle. Variations in degree of vigor of the vegetation of this formation are indicated by color variations. The redder the vegetation, the more vigorous the growth but the less suitable the grazing because the wetter conditions producing the vigorous growth are indicative of conditions favoring hoof-and-mouth and rinderpest, both serious cattle disease problems in Uganda (ref. 12). On better drained sites, the density of trees increases and the vegetation becomes a Tall Grassland with a Deciduous Tree Synusia covering 10-40 percent. The boundary between this and the preceding formation defines the northeastern limit of cultivation in Uganda. At higher elevations on the slopes of Mt. Napak savannas yield to an Evergreen Needle-leaved Woodland with Rounded Crowns dominated by Juniperus procera and Podocarpus gracilior. This woodland is quite distinctive from forests of similar composition which occur elsewhere in Uganda because of the difference between the lighter and more mottled color associated with the woodland and the darker smoother color of the forest.

Although differing in detail, certain similarities are evident between the sites in Uganda and south central Kansas (Figure 4C). This area, surrounded by cultivated land, is characterized by Medium Tall Grassland of Sod Grasses (ref. 13, Williams, pers. obsv.). Variation of plant density due to local topographic effects in this rugged area are evident. The plants are dormant on this image because it was acquired during a dry midsummer period and the native grasses grow actively only in the presence of suitable moisture supplies. In some parts of the area sand sage (Artemisia filifolia) is a common constituent of the vegetation, transforming the formation into a Medium Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs. This formation is readily distinguished from the preceding one because of the continued active growth of the shrubs in contrast to the dormancy of the grasses. The canyons of this area contain dense stands of eastern red cedars (Juniperus virginiana) which form an Evergreen Needle-leaved Forest with Conical Crowns. Topographic position and the use of seasonal coverage permit ready distinction of the preceding formation from the Cold-deciduous Alluvial Forest composed entirely of phreatophytes on the major river floodplains. The intense infrared reflection of the forests in this area is indicative of the relatively abundant water supplies in the forested areas.

Examination of supplementary sites in Wyoming, northeast Kansas, New Jersey, the Amazon Basin, Patagonia, the Sudan, and northern Australia provide no data contravening the results discussed in this section.

DISCUSSION AND CONCLUSIONS

From the illustrated examples and other test sites examined, it has become evident that the formations of the Unesco vegetation classification can be satisfactorily distinguished on LANDSAT MSS images, especially when used as color composites and judiciously chosen as to season. The imagery may therefore be used as a mapping base for the preparation of vegetation maps on the millionth scale. This outcome was to be expected since the chief criteria used in preparing the classification were based on density and vigor of vegetation and seasonal variations in growth behavior. It is exactly these factors which affect the return of energy to the satellite in the WAVELENGTHS to which the MULTISPECTRAL SCANNER on LANDSAT is sensitive.

The potential value of maps of this type for large-area planning is illustrated by the example from the Western Highlands of Papua New Guinea. Analysis of the imagery indicates a significant potential for the expansion of production of valuable commercial crops into an area not previously used for this purpose. Such analyses may be accomplished by either of two related methods. The first of these, illustrated by the Papua New Guinea example, uses the concept of analogous areas, interpreted from LANDSAT data through comparative analysis of vegetation and landforms. The second method relies on knowledge of the suitability of various crop plants as substitutes for natural vegetation communities. Formations may serve to effectively indicate which crop or crops have the greatest production potential in any area or to localize the areas where ground surveys are required.

One other significant value of periodic satellite coverage is clearly illustrated by Figures 4D and 4E. Human activity is resulting in continuing changes in the distributional relationships of agricultural and natural vegetation. Recently, center pivot sprinkler irrigation has expanded rapidly in southwestern Kansas. Much of this expansion has occurred in areas of Medium Tall Grassland Consisting Mainly of Sod Grasses. The two LANDSAT images indicate the marked increase in cultivation which has occurred between September 1972 and July 1974. Another formation, Medium Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs, is also present in this area. Few attempts to introduce irrigation into areas with this formation have been made and these attempts have met with limited success indicating the general unsuitability of areas with this formation for irrigated cultivation agriculture. Utilization of repeated LANDSAT coverage then permits periodic updating of maps, both for monitoring affects of changing land use as well as the more or less striking changes attributable to droughts or other natural environmental variations.

In conclusion, this study has found LANDSAT MSS imagery suitable for the interpretation of vegetation communities at the formation level of the Unesco classification. The utility of LANDSAT data has been illustrated by a series of interpretations which produced vegetation formation identifications or maps similar to those expected from existing literature. LANDSAT data was employed to analyze natural vegetation at small scales for sites in the humid tropics, arid and semi-arid sub-tropics and temperate zones, attesting to the universal applicability of the data source when used in conjunction with the Unesco Classification.

ACKNOWLEDGEMENTS

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LANDSAT Images Used

Frame Number	Acquisition Date	Quality	Cloud Cover (%)	Area
1026-00023	18 Aug. 72	Excellent	10	Papua, New Guinea
1027-00081	19 Aug. 72	Good	30	Papua, New Guinea
1081-01462	12 Oct. 72	Good	20	Mindoro, Philippines
1084-15431	15 Oct. 72	Excellent	10	Eastern Tennessee
1354-15431	12 Jul. 73	Good	10	Eastern Tennessee
1130-01293	30 Nov. 72	Good	0	Western Asutralia
1194-07284	2 Feb. 73	Good	0	Uganda
1194-07291	2 Feb. 73	Good	0	Uganda
1257-16464	6 Apr. 73	Good	0	South Central Kansas
1347-16455	5 July. 73	Excellent	0	South Central Kansas
1103-17300	3 Nov. 72	Good	10	Northwest Wyoming
1399-16332	26 Aug. 73	Excellent	0	Northeast Kansas
1079-15131	10 Oct. 72	Excellent	0	New Jersey
1008-13475	31 Jul. 72	Good	0	Amazon Basin, Brazil
1008-13481	31 Jul. 72	Good	0	Amazon Basin, Brazil
1237-13314	17 Mar. 73	Good	10	Patagonia, Argentina
1108-07482	8 Nov. 72	Good	0	Sudan
1020-01143	12 Aug. 72	Good	40	Northern Australia
1061-16570	22 Sep. 72	Excellent	0	Southwest Kansas
1709-16494	2 Jul. 74	Good	20	Southwest Kansas

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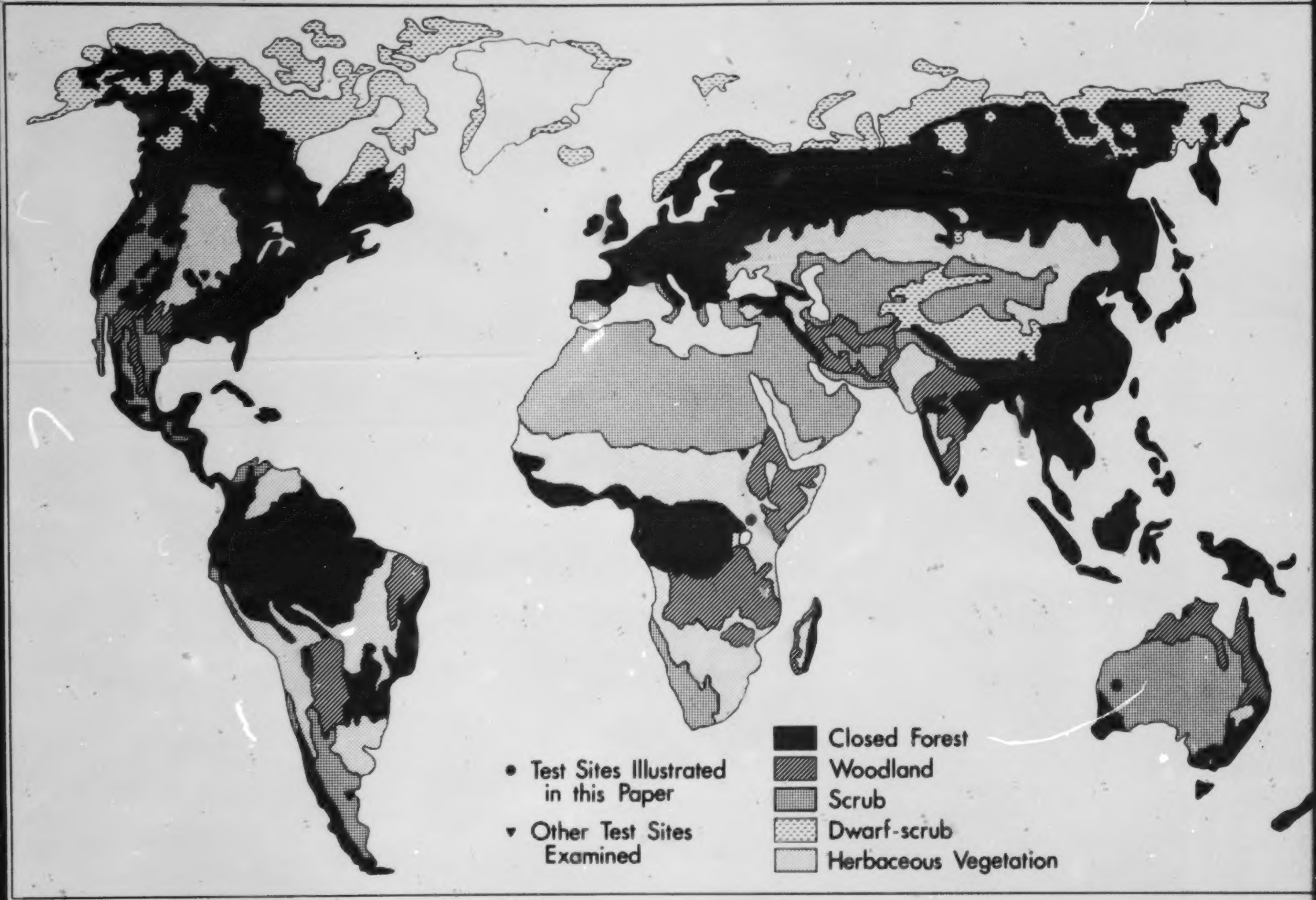
● Test Sites Illustrated in this Paper
▼ Other Test Sites Examined
■ Closed Forest
▨ Woodland
▦ Scrub
░ Dwarf-scrub
□ Herbaceous Vegetation

Figure 1. Location of test sites discussed in this paper with respect to the distribution of Formation Classes of natural vegetation. Vegetational data are after Sochava (ref. 14).

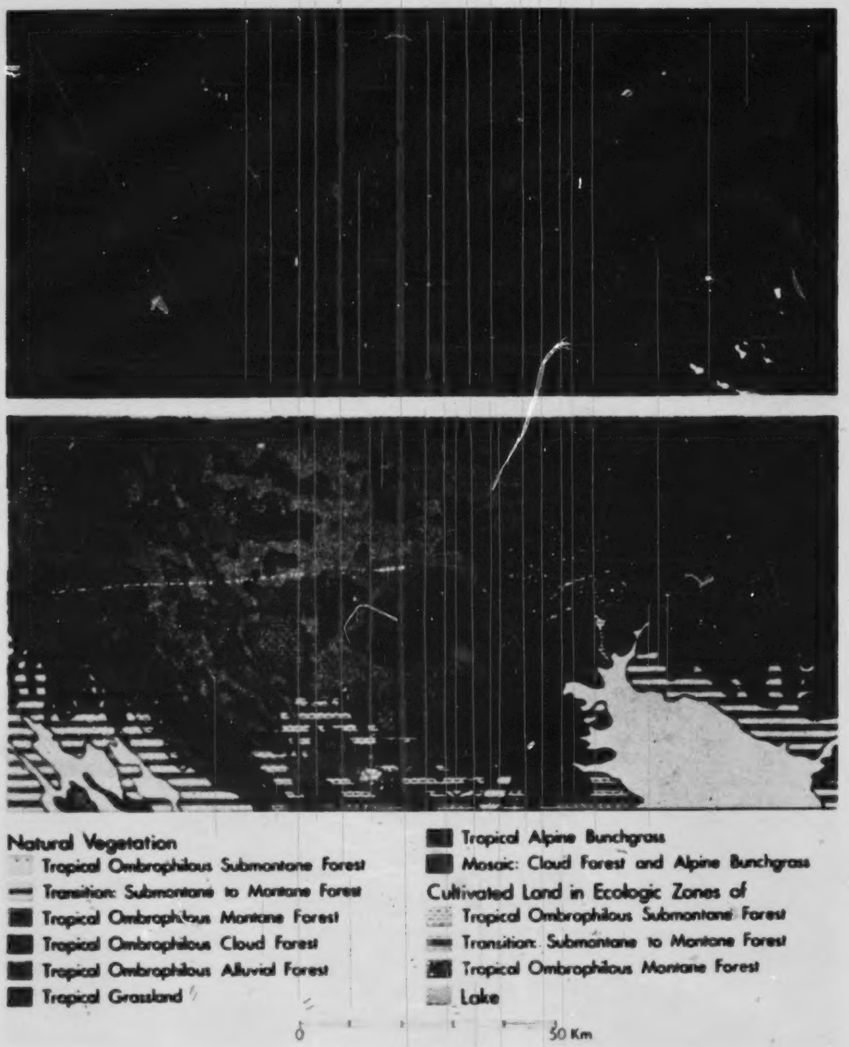
Natural Vegetation
Tropical Ombrophilous Submontane Forest
Transition: Submontane to Montane Forest
Tropical Ombrophilous Montane Forest
Tropical Ombrophilous Cloud Forest
Tropical Ombrophilous Alluvial Forest
Tropical Grassland
Tropical Alpine Bunchgrass
Mosaic: Cloud Forest and Alpine Bunchgrass
Cultivated Land in Ecologic Zones of
Tropical Ombrophilous Submontane Forest
Transition: Submontane to Montane Forest
Tropical Ombrophilous Montane Forest
Lake
0
50 Km

Figure 2. LANDSAT-1 image (1026-00023) of a portion of the Western Highlands of Papua New Guinea and the vegetation map prepared from this image according to the Unesco classification. It is evident by comparison of image and map that more detail is inherent in the image than may be reproduced on a map of this scale. Colors have been assigned to each cultivated area according to the apparent ecologic zone based on forest remnants and regrowth within the area.

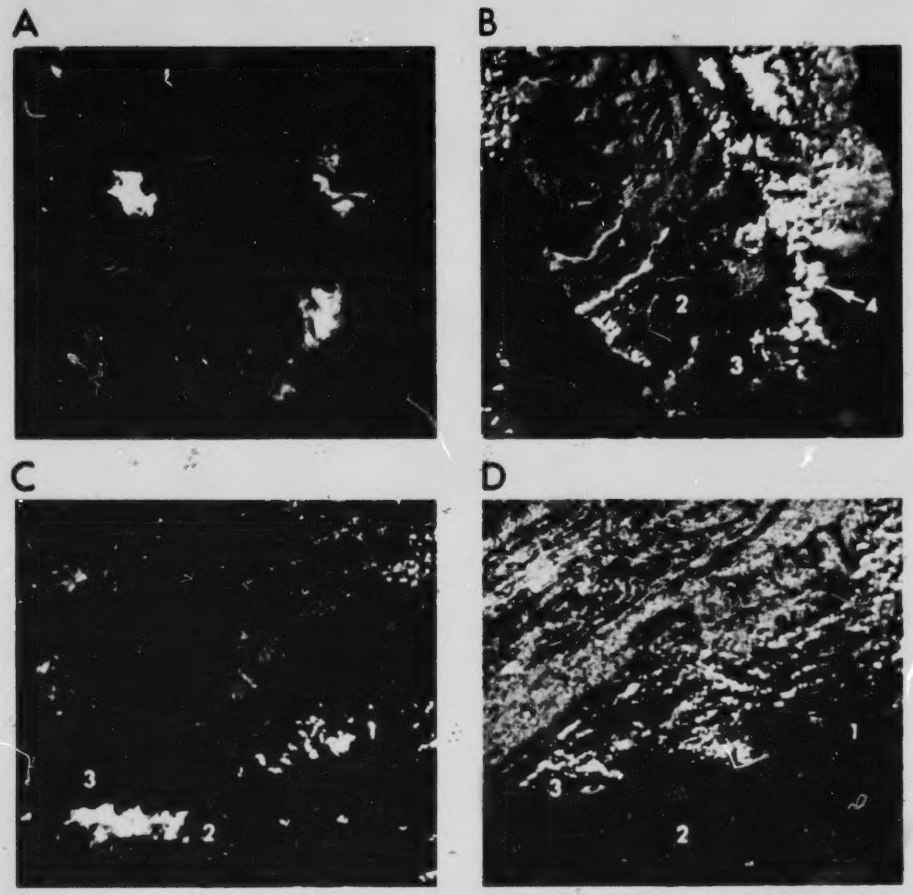

Figure 3. LANDSAT-1 images illustrative of other areas dominated by forest formations. A. Image (1027-00081) of another valley in the Western Highlands of Papua New Guinea, showing similar ecologic conditions to those on Figure 2. B. Image of Mindoro Island, Philippines (1081-014642) on which the following formations are annotated: 1) Tropical Grassland, 2) Needle-leaved evergreen subformation of the Tropical Ombrophilous Submontane Forest, 3) Tropical Ombrophilous Lowland Forest and 4) Mangrove Forest. C and D. Images showing seasonal contrast in the Great Smoky Mountains of the southeastern United States. Image C (1354-15431) was acquired 12 July 1973 while image D (1084-15431) was acquired 15 October 1972. Both frames are annotated as follows: 1) Evergreen Needle-leaved Forest with Conical Crowns, 2) Montane Cold-deciduous Forest, and 3) Cold-deciduous Broad-leaved Forest with Evergreen Needle-leaved Trees.

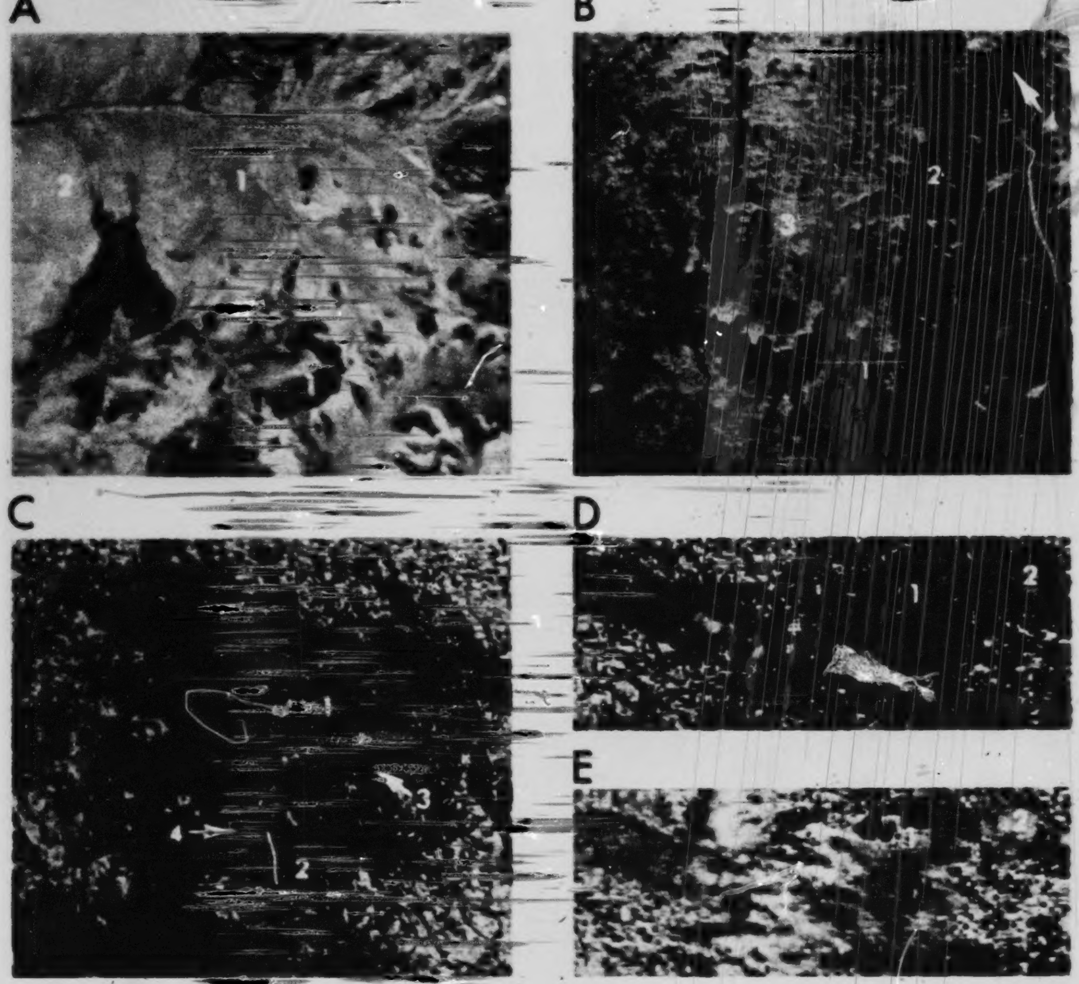

Figure 4. LANDSAT-1 images illustrative of areas of predominantly scrub or herbaceous vegetation. A. Image (1130-01293) of interior Western Australia with the following annotations: 1) Semi-deciduous Subdesert Shrubland and 2) Medium-Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs. B. Image (1194-07284) of northeastern Uganda annotated as follows: 1) Tropical Grassland, 2) Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs, 3) Tall Grassland with a Deciduous Tree Synusia Covering 10-40 Percent and 4) Evergreen Needle-leaved Woodland with Rounded Crowns. C. Image (1347-16455) of south-central Kansas with the following types annotated: 1) Medium Tall Grassland of Sod Grasses, 2) Medium Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs, 3) Evergreen Needle-leaved Forest with Conical Crowns, and 4) Cold-deciduous Alluvial Forest. D and E. This pair of images (1061-16570 and 1709-164[illegible]) of southwestern Kansas acquired in 1972 (D) and 1974 (E) illustrates replacement of a Medium Tall Grassland by sprinkler-irrigated cropland in the areas marked 1. Areas marked 2 are Medium Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs.

MILLIONTH SCALE

Vocabulary - Define the following terms in detail.

- Scale
- Land-use
- Unesco classification
- Closed forest
- Woodland
- Scrub
- Dwarf-scrub
- Herbaceous
- Physiognomy
- km^2
- 1:20,000
- 50 X
- Artemisia filifolia
- Juniperus virginiana
- Multispectral scanner system
- Bands 5 and 7
- Mosaic
- Phragmites karka
- Pyrethrum
- Miscanthus floridulus
- Imperata cylindrica
- Picea
- Abies
- Acacia aneura
- Cyperus papyrus
- Juniperus procera
- Podocarpus garcilior

Questions - Answer the following inquires in detail.

1. What is the Unesco System?
2. Why is the classification based upon physiognomic rather than floristic criteria?
3. What are the five formation classes of Unesco?
4. Explain the compilation method in detail.
5. Explain primary mapping in detail.
6. How did LANDSAT mapping scales assist the researchers?
7. What are the basic relationships between an image and the map?
8. What was the real time agricultural assistance from this project as well as the determination of future agricultural needs through imagery acquisition?
9. The article discusses several species of plant life. How are these plants situated on a hill? Canopy effect? Hammock? Stair-step effects?
10. Why is it necessary to periodically update the new maps?

Discussion Topics

1. Why is it important to have a standard classification system in mapping?
2. Explain scales in detail.

CHANGE IN LAND USE IN THE PHOENIX (1:250,000) QUADRANGLE, ARIZONA BETWEEN 1970 AND 1973: ERTS AS AN AID IN A NATIONWIDE PROGRAM FOR MAPPING GENERAL LAND USE

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ABSTRACT

Changes in land use between 1970 and 1973 in the Phoenix (1:250,000 scale) QUADRANGLE in Arizona have been mapped using only the images from ERTS-1, tending to verify the utility of a standard land use classification system proposed for use with ERTS images. ERTS 9 x 9 transparencies, interpreted by several techniques, were used to update a land use map previously compiled with 1970 air photos. Type of changes detected have been (1) new residential development of former cropland and rangeland; (2) new cropland from the desert; and (3) new reservoir fill-up. The seasonal changing of vegetation patterns in ERTS has complemented air photos in delimiting the boundaries of some land use types. Inasmuch as air photos normally are a year or more out of date, ERTS provided currency.

TEXT

ERTS images, in combination with other sources of information, can assist in mapping the generalized land use of the fifty states by the standard 1:250,000 quadrangles. Several states are already working cooperatively in this type of mapping. This monitoring of land use change can be of value to planners and resource managers at Federal, state, and regional levels, both for resource development and environmental protection in broad areas of the United States. The ERTS images focus attention on those areas requiring more intensive study.

The objectives of ERTS investigation number SR 186 have been (1) to test the interpretability of ERTS-1 images for use in the mapping of generalized land use, and (2) to test the applicability of ERTS-1 images in detecting changes and updating maps.

After using the ERTS images, it is apparent that they will be of help, in combination with other sources of information, in mapping the generalized land use of the fifty states by 1:250,000 quadrangles. A cooperative program has already been established to do this with several states and multi-state regional commissions. The ERTS coverage could be of particular value in selecting which quadrangles are in greatest need of update in the first cycle of revision.

Figure 1 is the most recent map showing land use for most or all of the United States. It presents information that was collected by conventional means over a period of several years, and it was in part out of date at the time that it was published by the USGS in the National Atlas of the United States. With the advent of earth satellite sensors, supplemented by air photos, it became possible to monitor land use changes on a nearly real-time basis. It was believed that to reduce costs, the mapping and updating should be computerized and should be built around the standard 1:250,000-scale TOPOGRAPHIC QUADRANGLES, the largest scale of maps for which we have complete coverage of the fifty states.

The Phoenix quadrangle in Arizona (see Figure 2) was selected as the pilot project, and it would also serve as a test of land use mapping in arid lands. Figure 2 shows a 2 x 2 matrix of four quadrangles in southern Arizona. The Phoenix quadrangle is the one to the northwest. The other three were investigated under sponsorship of the EROS Program as a complementary effort.

The first step in producing a computerized map of land use is to compile by hand, as shown in Figure 3, while interpreting high-altitude air photos, supplemented by satellite imagery. This particular hand-compiled map of land use in the Phoenix Quadrangle was drawn from U-2 photos taken in November 1970.

The data from the land use maps were read into a computerized data bank along with data on land ownership, soils, drainage, and census codes for state, county and tracts as listed in Figure 4.

Figure 5 illustrates the first example of an automated plot of land use from the computer data bank. The general land uses are shown in color. The black plate from the standard topographic quadrangle has been overlain to provide place names, LINEAR PATTERNS and much of the marginal information.

Figure 6 shows a blow-up of the eastern edge of that last map, showing most of the Phoenix metropolitan area. The colors represent the first level of our land use classification system, and different symbols are used to show the second level of detail.

Figure 7 presents the land use classification system which was used in the Arizona study. It has been published in USGS Circular 671. The first level was designed for interpreting satellite imagery; the second level for high-altitude aircraft photography. It is open ended for users to add other levels as desired.

An example of one color plate of the land use map is presented in Figure 8. Our Calcomp 763 plotter plotted this cropland plate. The dense symbols are tree crops, in this case citrus, and the lighter patterns are other crops. Changes in the land use record can be made very simply by card input to update specific cells.

Change detection has been an important part of our work, with special emphasis on our ERTS experiment. Of the many techniques that we have used to interpret ERTS images, the one that worked best was the seasonal comparison of ERTS color composites.

Figure 9 is a color composite of the Phoenix area in August 1972, right after the launch of ERTS-1. Our processing got better later, but desert vegetation looks drab, colorless during the summer. The irrigated fields near Phoenix show red. Here the MSS 4, 5, and 6 bands are combined.

An October view of the same area is shown in Figure 10. Improved color results from the substitution of the 7 band in place of the 6 band in the composite. However, the natural vegetation still looks dry and colorless before the beginning of the primary rainy season.

Figure 11 is a February ERTS scene during a very rainy winter. The natural grasses in the dessert show bright red, and desert brush appears redder and lusher. These are bands 4, 5, and 7.

Figure 12 is the May ERTS scene of the same area. The natural grasses are beginning to brown out. The pattern of Phoenix urban land use is particularly clear in this ERTS composite. The upper end of the new Painted Rock Reservoir is visible near the southwest corner. Study of reservoir fluctuations may be one use of ERTS.

Figure 13 is a September ERTS scene from the pass west of the one shown in the previous three figures. In September, the Painted Rock Reservoir downstream from Gila Bend has not yet started to fill. The fall vegetation is too drab to silhouette man-made features well; however, the mine tailings and pits at Ajo show up clearly.

An I^2S COLOR ADDITIVE VIEWER was used to create experimental color composites. This viewer handles 70 mm film chips. As illustrated in Figure 14, to get greater magnification, 70 mm chips were cut out of 9 x 9 transparencies, and these were mounted in the film viewer.

Figure 15 illustrated what the chip looks like when blown up onto the display screen of the I^2S viewer. At a scale of 1:380,000 on the scope, it resembled the 1:250,000 scale of the 1970 hand-drawn map that we were trying to update.

When that MSS 5 band was combined with bands 4 and 6 in the viewer, the color composite shown in Figure 16 was created. This is a photograph of the display scope, one way to keep a record of experimental settings.

When ERTS images from different time periods were overlain using different color filters, it was expected that differences of changes would be enhanced. They were as shown in Figure 17, but primarily it enhanced differences in stage of vegetation growth, not differences in general land use. This technique was a little disappointing. Quick-flip technique also showed too much clutter.

We also tried density slicing of an ERTS 5 band image using a Data Color Viewer as shown in Figure 18. This gave us experience in planning for the use of computer compatible tapes which are now being investigated. We learned to focus in on areas of relatively homogenous use, that is, urban or rural, but not both. In Figure 18, by focussing-in on downtown Phoenix, business streets and commercial-industrial districts are enhanced, but it is still cluttered.

From all these image interpretation techniques, particularly the color composites of the ERTS images, we compiled maps of change detected using ERTS. Early efforts had many inaccuracies, but as seasonal changes in vegetation were monitored by ERTS, a much more accurate delineation was possible. The muted colors shown in Figure 19 are the original 1970 land use map. The brighter colors are the changes detected using only ERTS images. The red is new urban, the green is new cropland, and the dark blue is new water surfaces, as shown in the legend in Figure 20.

As a check of accuracy, we did the same change detection shown in Figure 21, using U-2 air photographs taken November 1972. This map of change is more detailed than the ERTS change map, but the ERTS map is more up-to-date reflecting changes of the past few months. The total areas of change are similar. ERTS and air photos complement each other. ERTS certainly focusses attention on rapidly-changing areas.

In Figure 22, the total change in the Phoenix quadrangle has been summarized from data bank in this matrix of change "from" and "to".

The utility of having other factors combined in the data bank is illustrated in Figure 23 where that last change matrix is divided up in four matrices by land ownership classes, private, state, public lands, and Indian lands.

As examples of queries that we have made to the Phoenix data bank, we asked, how much land has been lost from agriculture to urban use in Maricopa County between February and November 1970? The answer: 1760 square kilometers. Used for urban? 349 square kilometers. And these areas could be plotted as maps.

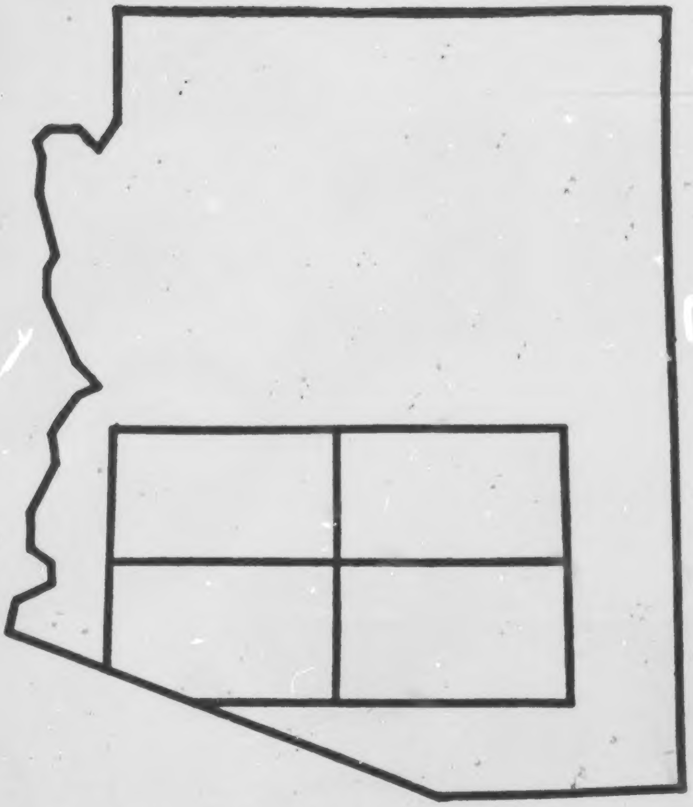
In the past few weeks, more effort has been given toward plotting the original digitized polygons in map form, thus gaining greater accuracy over the cellular maps. In Figure 24, the land use patterns on the east side of Phoenix are outlined as polygons by a Calcomp 763 plotter.

In Figure 25, land use polygons are filled-in automatically with colored symbols. In this case, the area is around Gila Bend, Arizona.

We have the capability to convert the polygons automatically to cells in order to exploit our existing soft-ware for statistical analysis.

Primarily we have been creating an array of procedures to be applied to various tasks. The USGS has been attempting to work with individual states, mostly through multi-state regional organizations and have established cooperative working arrangements with the Ozark Regional Commission and the Appalachian Regional Commission to map parts of their regions, using the procedures that I have just described, developed originally for the Phoenix Quadrangle, utilizing all available sources of information, including ERTS images. The ERTS images provide currency and improved interpretation of land use where seasonally-changing patterns help to indicate use.

1. The land use map from the National Atlas of the United States. This is the most recent map of land use covering all or most of the country, but it took several years to compile and is many years out of date.



2. An orientation map of the four 1:250,000 scale quadrangles currently being worked on in Arizona. The Phoenix quadrangles is the one on the northwest.

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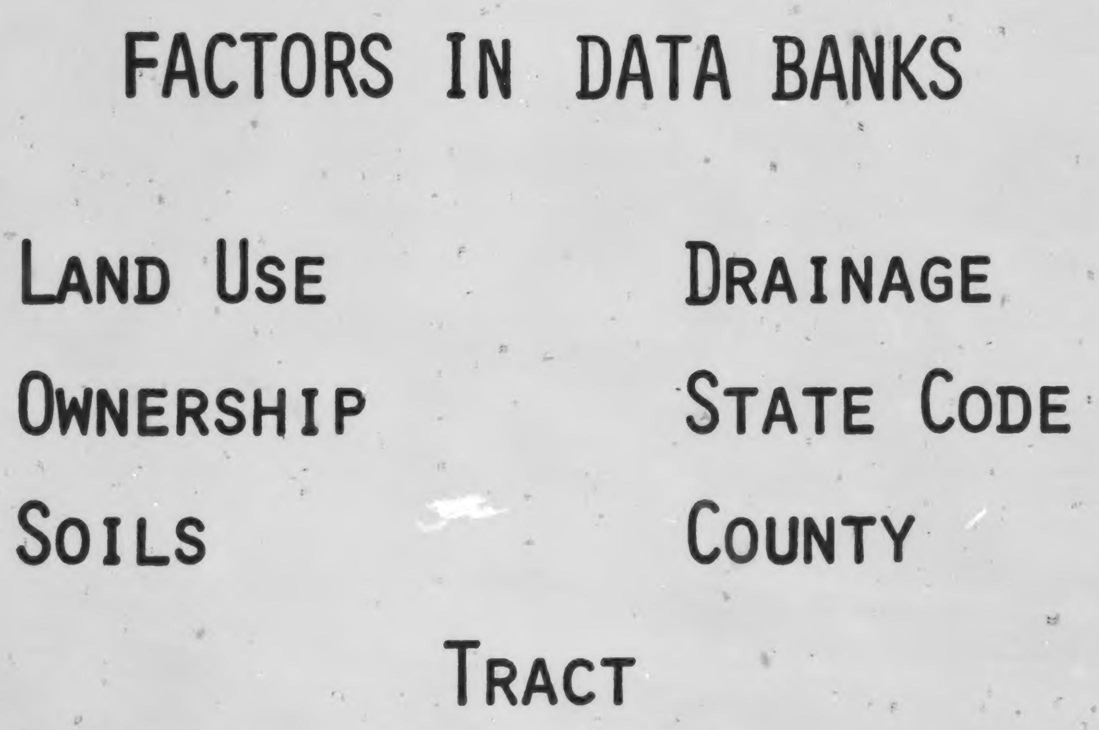
3. Hand-drawn land use map of the entire Phoenix Quadrangle (scale 1:250,000), compiled from aerial and satellite photography. The ERTS images were compared to this type of map in order to detect changes. This map is merely an interim working step in digitizing the computerized model and map.



FACTORS IN DATA BANKS

LAND USE

OWNERSHIP

SOILS

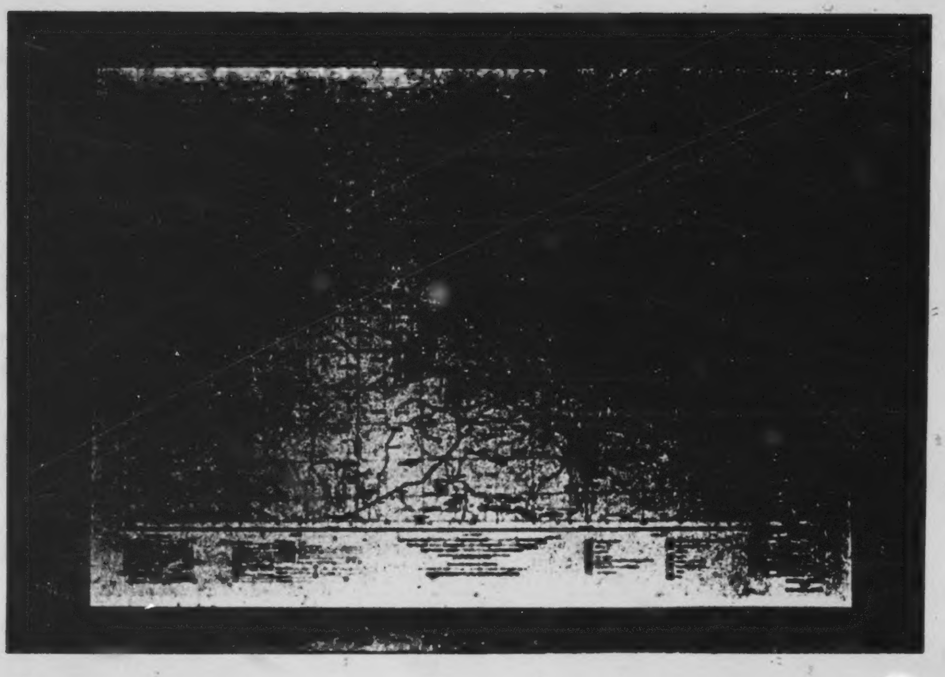
DRAINAGE

STATE CODE

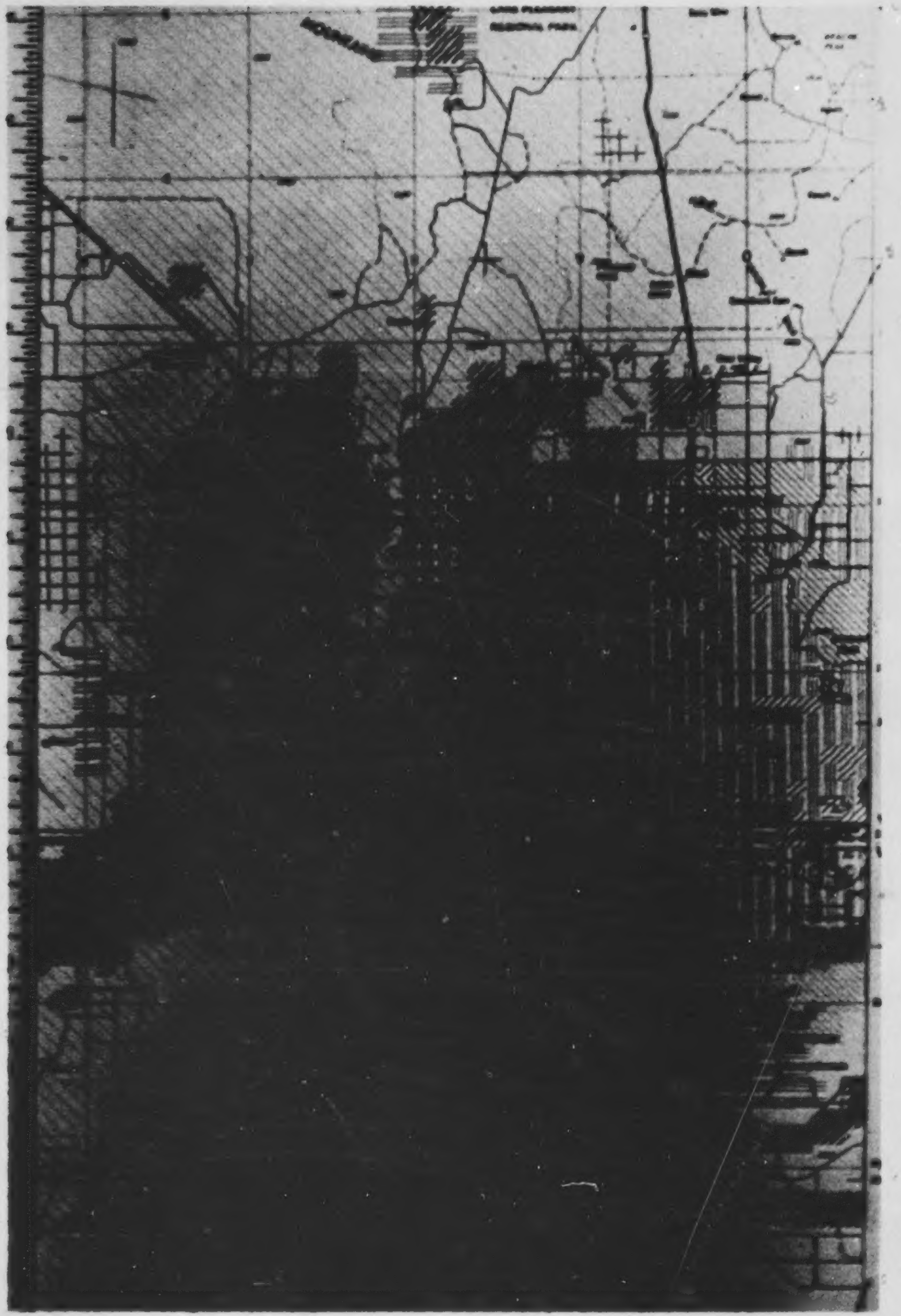
COUNTY

TRACT

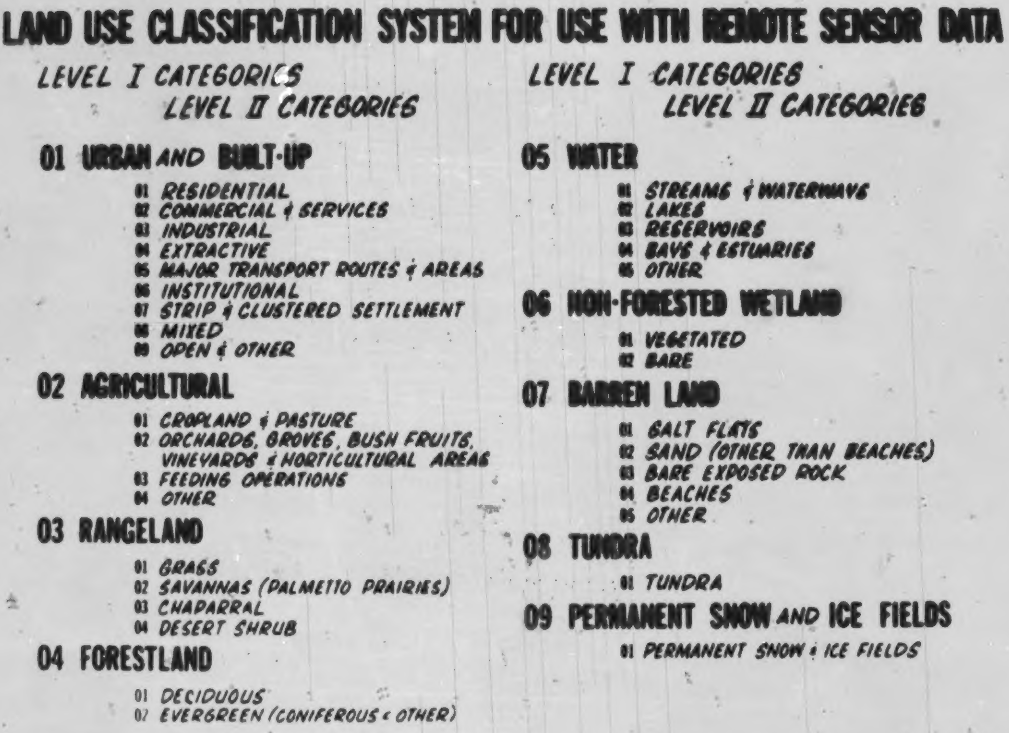
4. A list of the factors recorded in the computer data bank for the Phoenix Quadrangle. The date of the land use information is also recorded.



5. Land use map of the entire Phoenix (1:250,000) Quandrangle plotted automatically from the computerized data bank and overlain with the black plate from the standard topographic sheet. This data bank and map represents land use in 1970; it will be updated through use of ERTS images.



6. Land use map plotted automatically from a computer data bank of the Phoenix Quadrangle. This shows the City of Phoenix on the eastern edge of the map. The changes detected in the ERTS images will be used to update this data bank.



LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA

LEVEL I CATEGORIES
  LEVEL II CATEGORIES

01 URBAN AND BUILT-UP
- 01 RESIDENTIAL
- 02 COMMERCIAL & SERVICES
- 03 INDUSTRIAL
- 04 EXTRACTIVE
- 05 MAJOR TRANSPORT ROUTES & AREAS
- 06 INSTITUTIONAL
- 07 STRIP & CLUSTERED SETTLEMENT
- 08 MIXED
- 09 OPEN & OTHER

02 AGRICULTURAL
- 01 CROPLAND & PASTURE
- 02 ORCHARDS, GROVES, BUSH FRUITS, VINEYARDS & HORTICULTURAL AREAS
- 03 FEEDING OPERATIONS
- 04 OTHER

03 RANGELAND
- 01 GRASS
- 02 SAVANNAS (PALMETTO PRAIRIES)
- 03 CHAPARRAL
- 04 DESERT SHRUB

04 FORESTLAND
- 01 DECIDUOUS
- 02 EVERGREEN (CONIFEROUS & OTHER)

LEVEL I CATEGORIES
  LEVEL II CATEGORIES

05 WATER
- 01 STREAMS & WATERWAYS
- 02 LAKES
- 03 RESERVOIRS
- 04 BAYS & ESTUARIES
- 05 OTHER

06 NON-FORESTED WETLAND
- 01 VEGETATED
- 02 BARE

07 BARREN LAND
- 01 SALT FLATS
- 02 SAND (OTHER THAN BEACHES)
- 03 BARE EXPOSED ROCK
- 04 BEACHES
- 05 OTHER

08 TUNDRA
- 01 TUNDRA

09 PERMANENT SNOW AND ICE FIELDS
- 01 PERMANENT SNOW & ICE FIELDS

7. The land use classification system designed for use with ERTS images (Level I) and with high altitude NASA aerial photographs (Level II). It was found that some of the Level II categories could be distinguished from ERTS images most of the time. The classification system is being used with the Phoenix Quadrangle project.

8. Example of an automated plot in the form of the color plate for cropland. Tree crops are indicated by denser symbols. Combining of such color plates produces the colored map shown in Figures 5 and 6.

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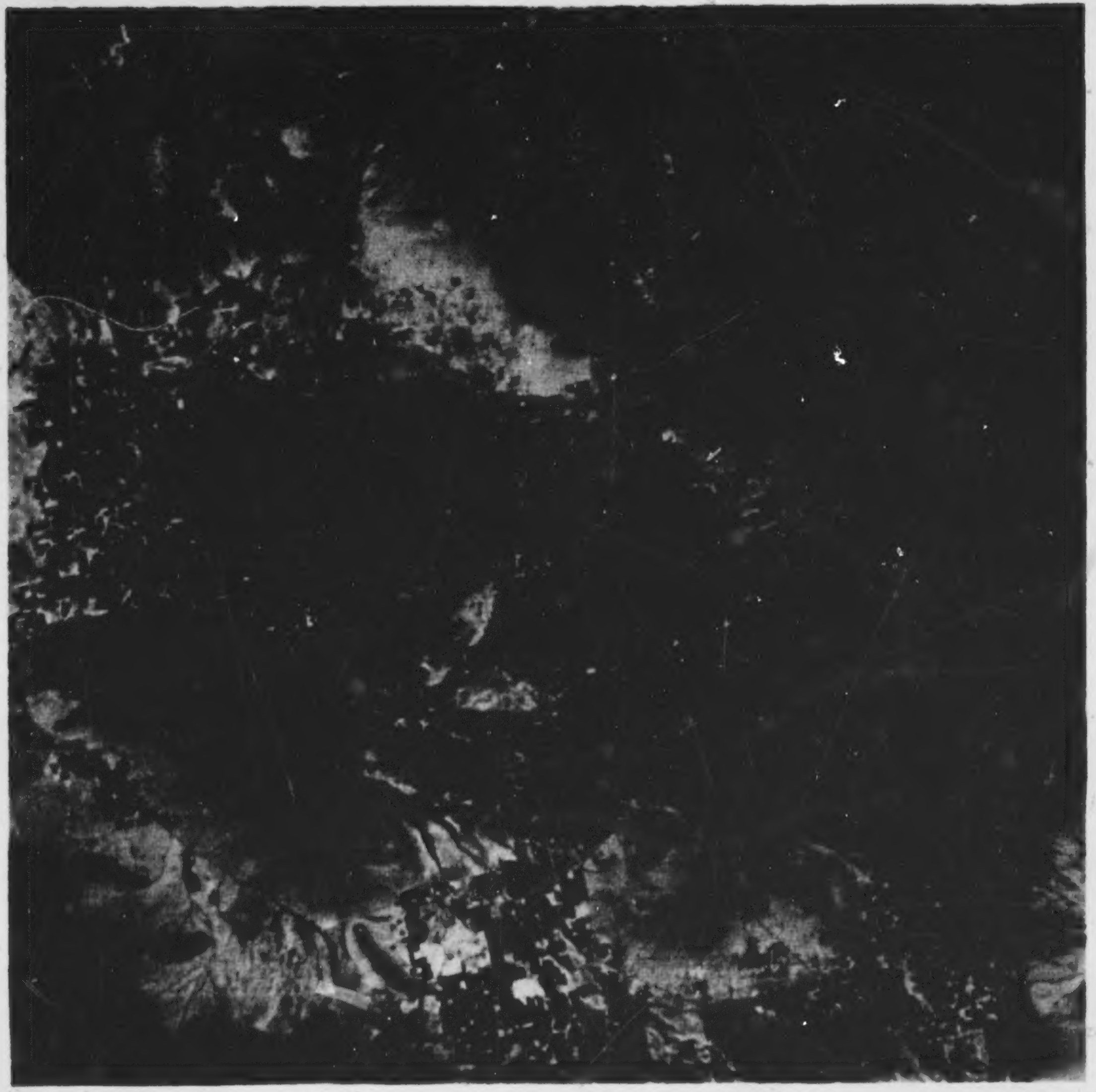
9. Print of ERTS color composite with an approximate scale of 1:1,000,000. This shows Phoenix and vicinity on August 23, 1972. This was one of the first ERTS frames and the processing was not as good as it became later. Nevertheless, the dryness, i.e., absence of red tones, can be seen as the desert vegetation has withered during the summer dry season. Mines appear as blue scars. Color composite was made with bands 4, 5, and 6.



10. Print of an ERTS color composite with an approximate scale of 1:1,000,000. This shows Phoenix and vicinity on October 16, 1972. The desert shrubs are dry and colorless at the end of the dry season. Many fields are fallow along the edge of the desert. Only by comparing crop patterns for all seasons can we accurately delineate the land use boundaries. Color composite was made with bands 4, 5, and 7.

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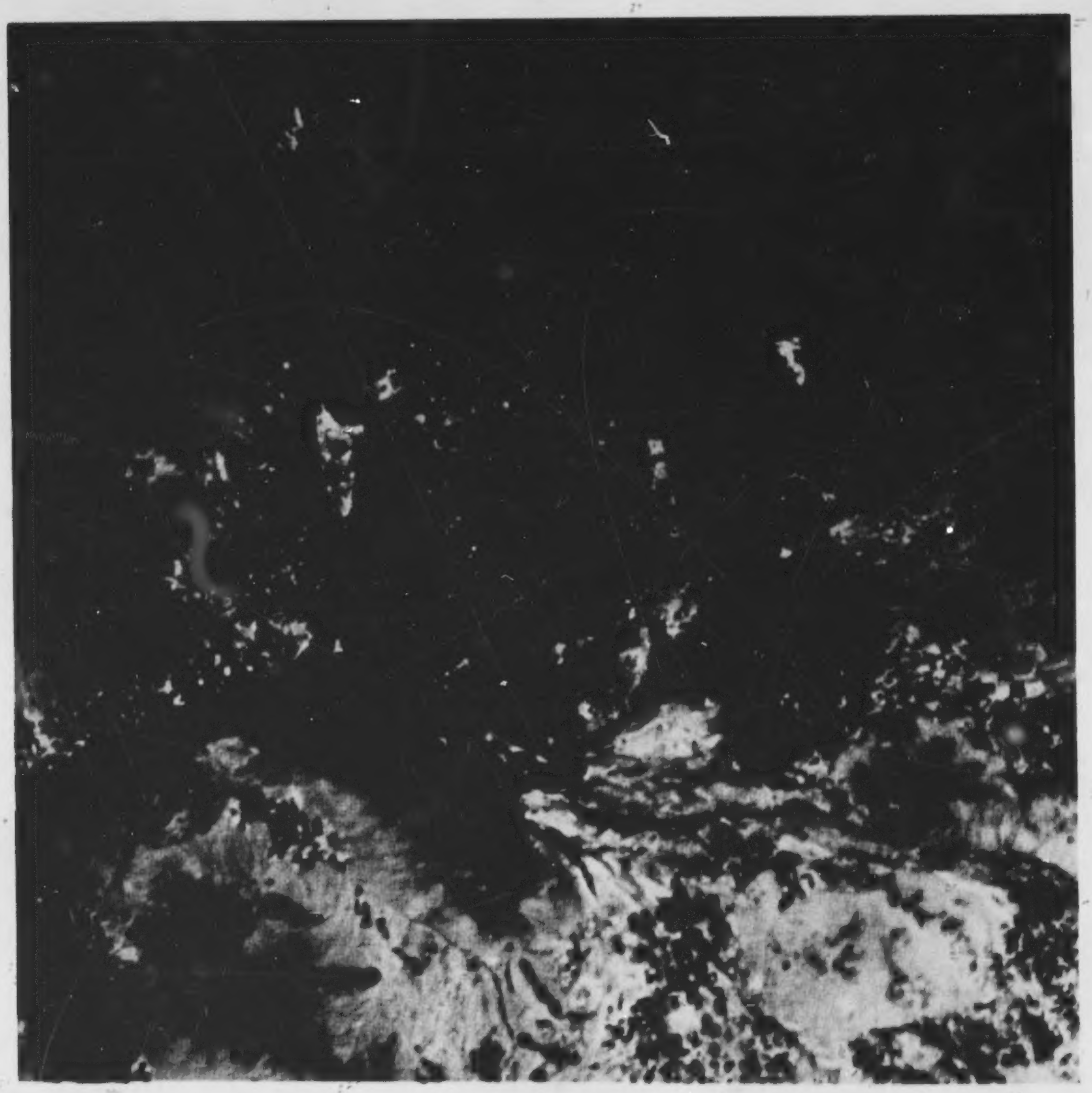
11. Print of an ERTS color composite with an approximate scale of 1:1,000,000. This shows Phoenix and vicinity on February 19, 1973. This shows lush desert grasses present during a particularly wet rainy season. Note that the irrigated crops are not redder than in the images from other seasons. Color composite was made with bands 4, 5 and 7.



12. Print of an ERTS color composite with approximate scale of 1:1,000,000. This shows Phoenix and vicinity on May 2, 1973. The urban patterns within Phoenix show up as blue line commercial streets. With ten times magnification, the textures of industrial districts and the central business district are discernible. The residential areas are purplish pink. The Painted Rock Reservoir is full of water for the first time. Its upper end is visible on the west edge of the image. Salt River also has surface water, revealing channel locations, a rare sight. Color composite was made with bands 4, 5, and 7.

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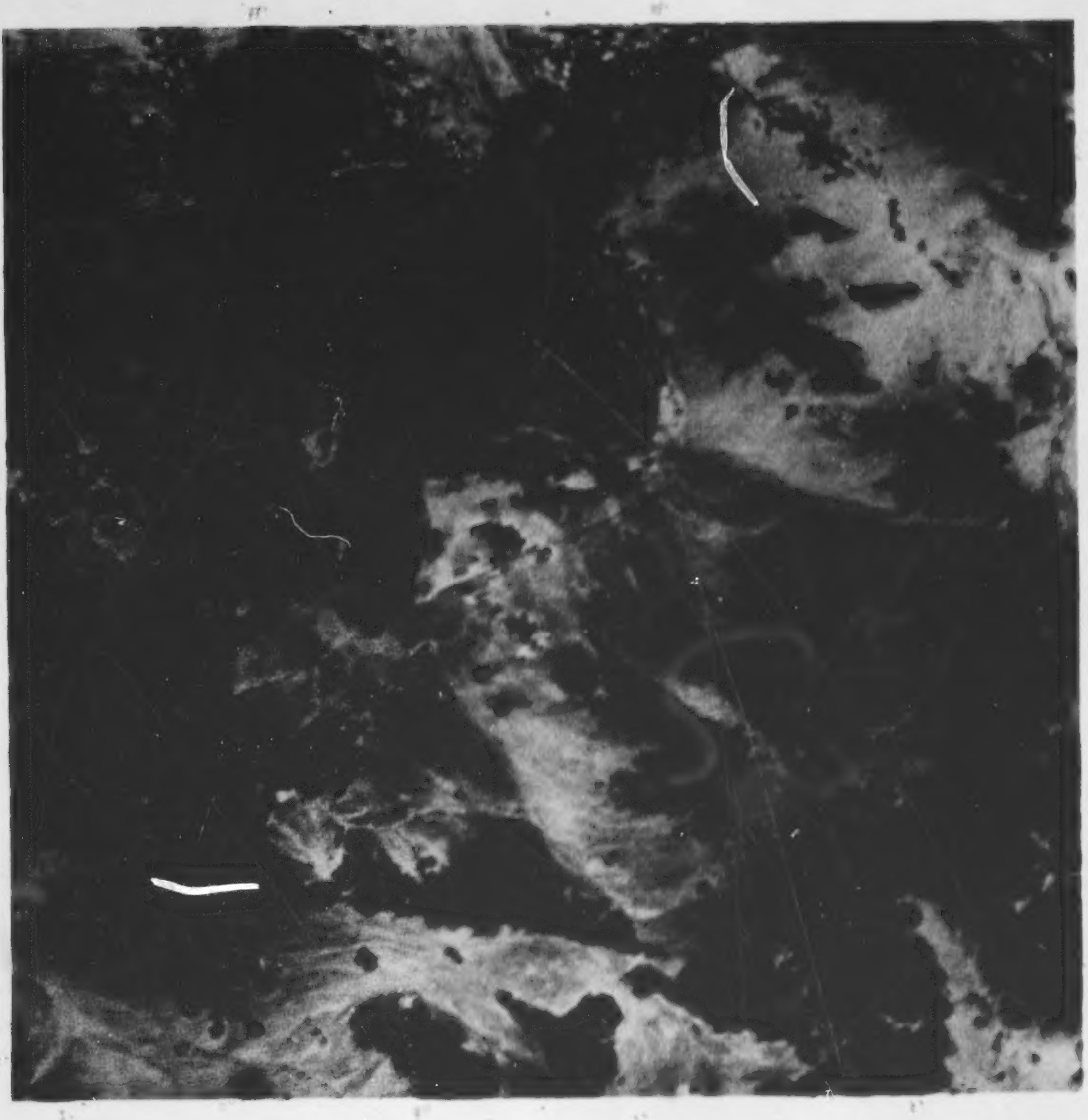
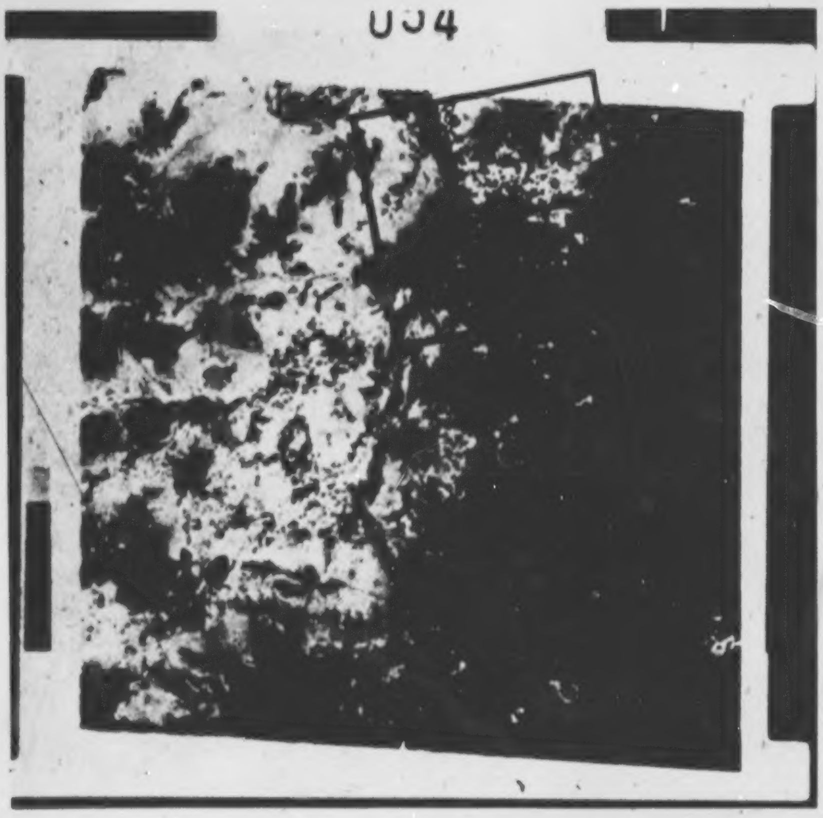
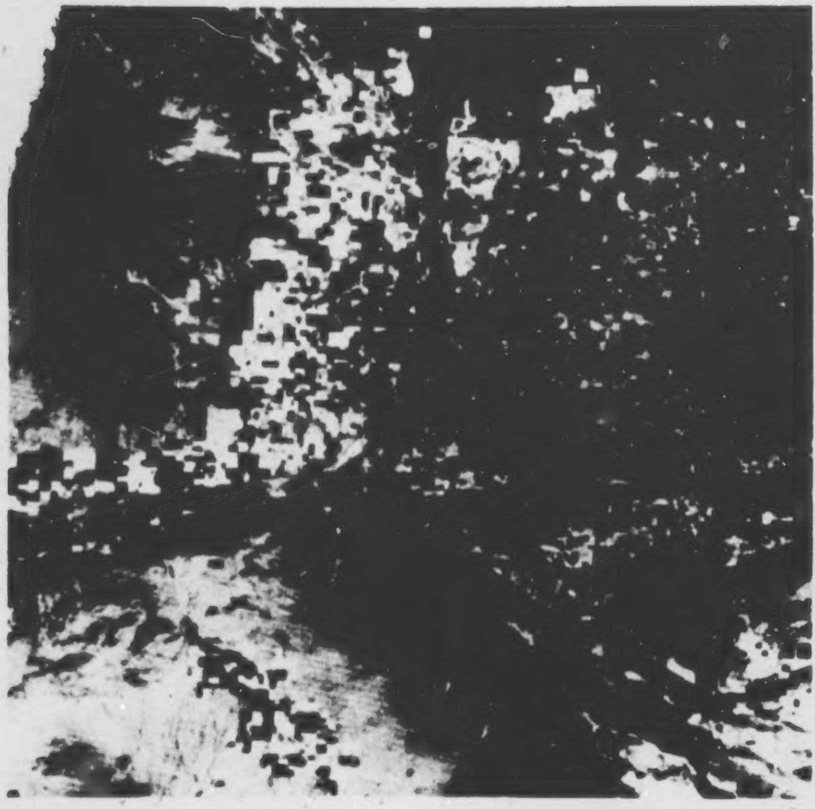


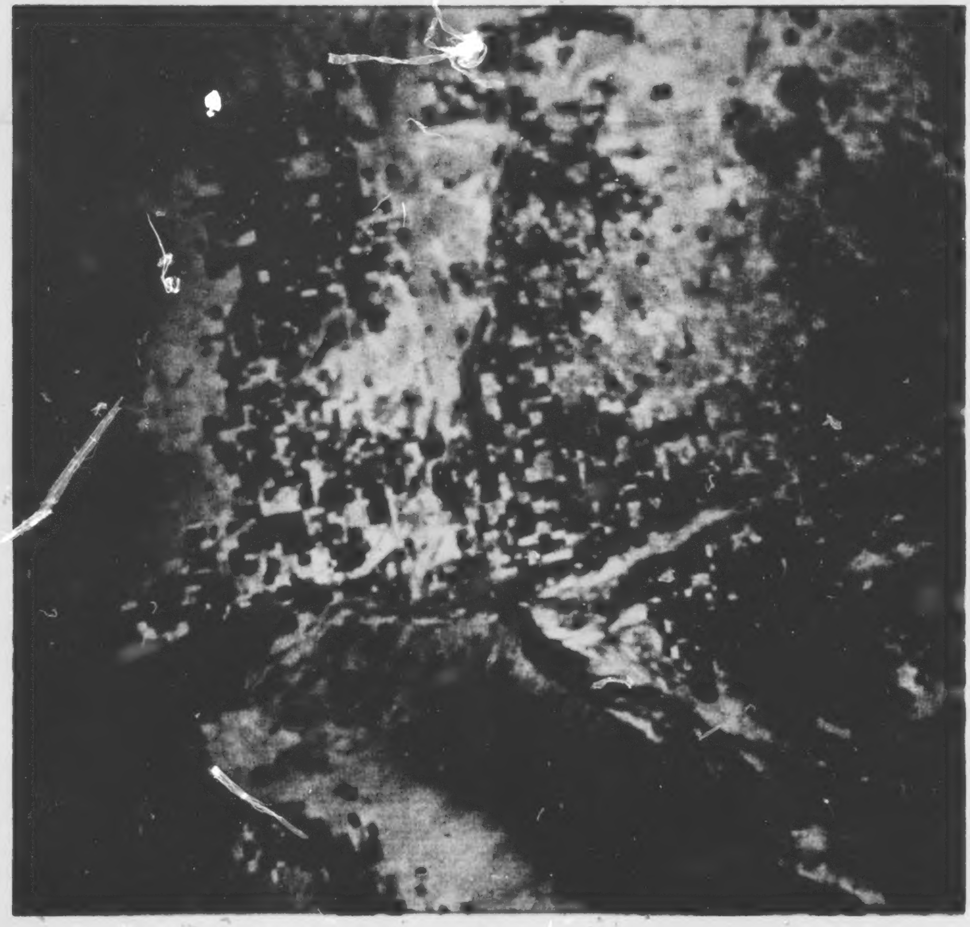
13. Print of an ERTS color composite with approximate scale of 1:1,000,000. This shows much of the Phoenix Quadrangle southwest of Phoenix on November 4, 1972. Notably it showed the Painted Rock Reservoir before it was allowed to fill. The May 1973 image shows the upper end of that reservoir full of water. Note the open pit copper mines showing clearly at Ajo in the lower right of the image. Color composite was made with bands 4, 5, and 7.



14. Example of how a 70 mm chip is cut out of a 9 x 9 transparency showing south-central Arizona. The 70 mm chip is to be used in an I^{2}S Color Additive Viewer where it will be magnified from 1:1,000,000 to a scale of about 1:380,000 on the display scope of the viewer. This scale approximates the base mapping scale of 1:250,000 used in the Phoenix Quadrangle project.



15. Examples of a three-times magnification of the 70 mm chip shown in the previous illustration. This approximates its scale on the display screen of the I^2S viewer, however, in the viewer it would be combined into a color composite with identical chips from other bands. This is a band 5 image of the Phoenix area.



16. Example of a color photograph taken of the display screen of the I^2S Color Additive Viewer. This one is the ERTS color composite (bands 4, 5, and 6) of the west side of Phoenix taken in November 1972. Scale approximately 1:300,000.

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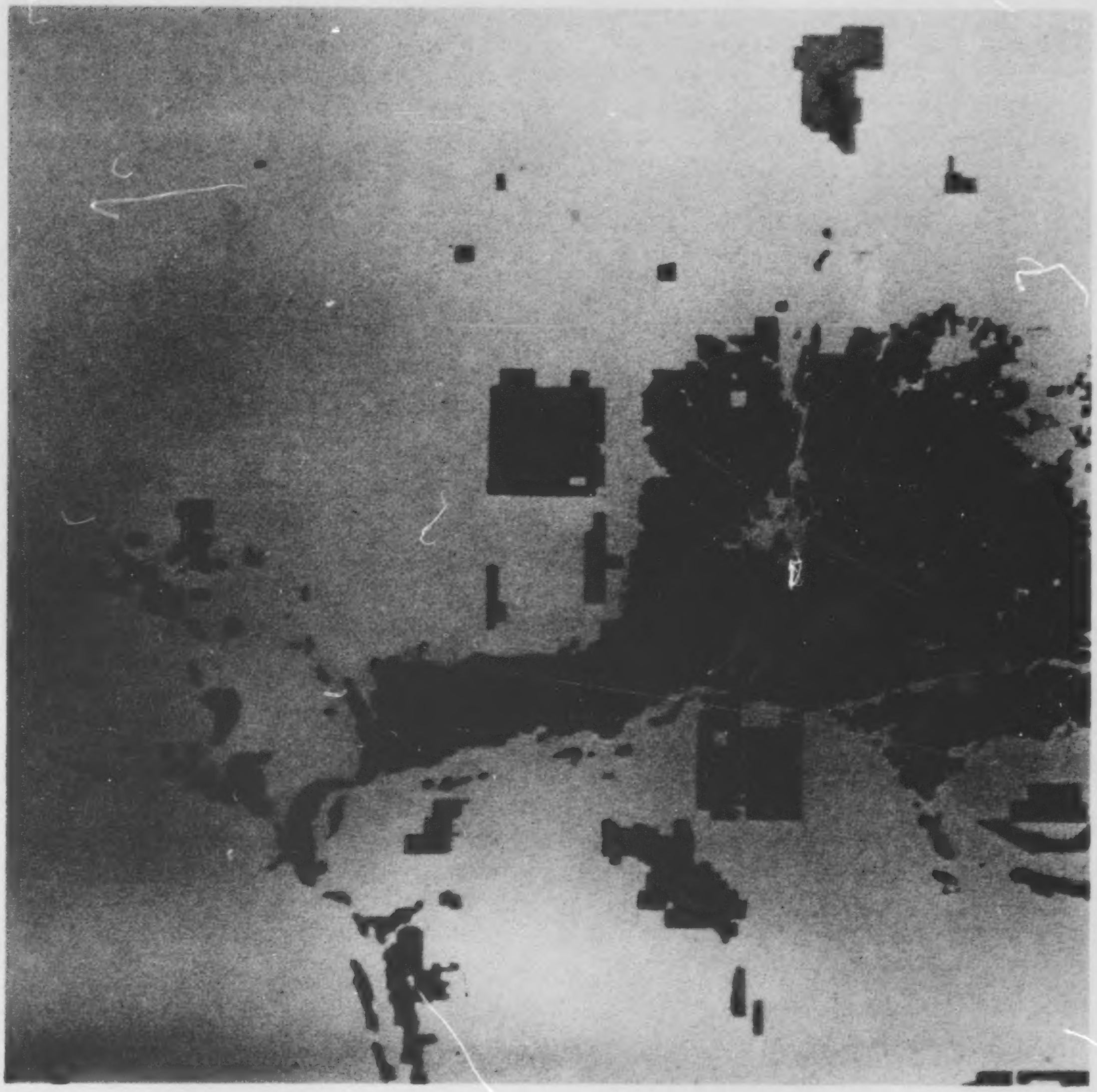
17. An attempt at change detection by using ERTS images two months apart with different color filters. Different satellite positions causes some blurring and clutter. In general, unchanged areas cancel out as brown. Yellow or blue colored areas indicate possible change, but most is due to different stages of the agricultural cycles, not change in land use. These were band 5 images taken west of Phoenix in August and October 1972. A one year change will be tested.

18. Using the Data Color Viewer to focus in on central Phoenix and to slice gray-scale densities, non-vegetated commercial and industrial districts appear dark blue, business streets red, and residential areas pale blue and green. An ERTS band 6 was used.



19. Change in land use detected using only ERTS images obtained throughout the period August 1972 and May 1973. The area shown is the eastern half of the Phoenix Quadrangle. It is important that total areas of urban growth detected by aerial photography or by satellite sensing are similar and the location of the primary clusters are essentially the same. New areas of change since the date of the aerial photos show how the two collection systems complement each other.

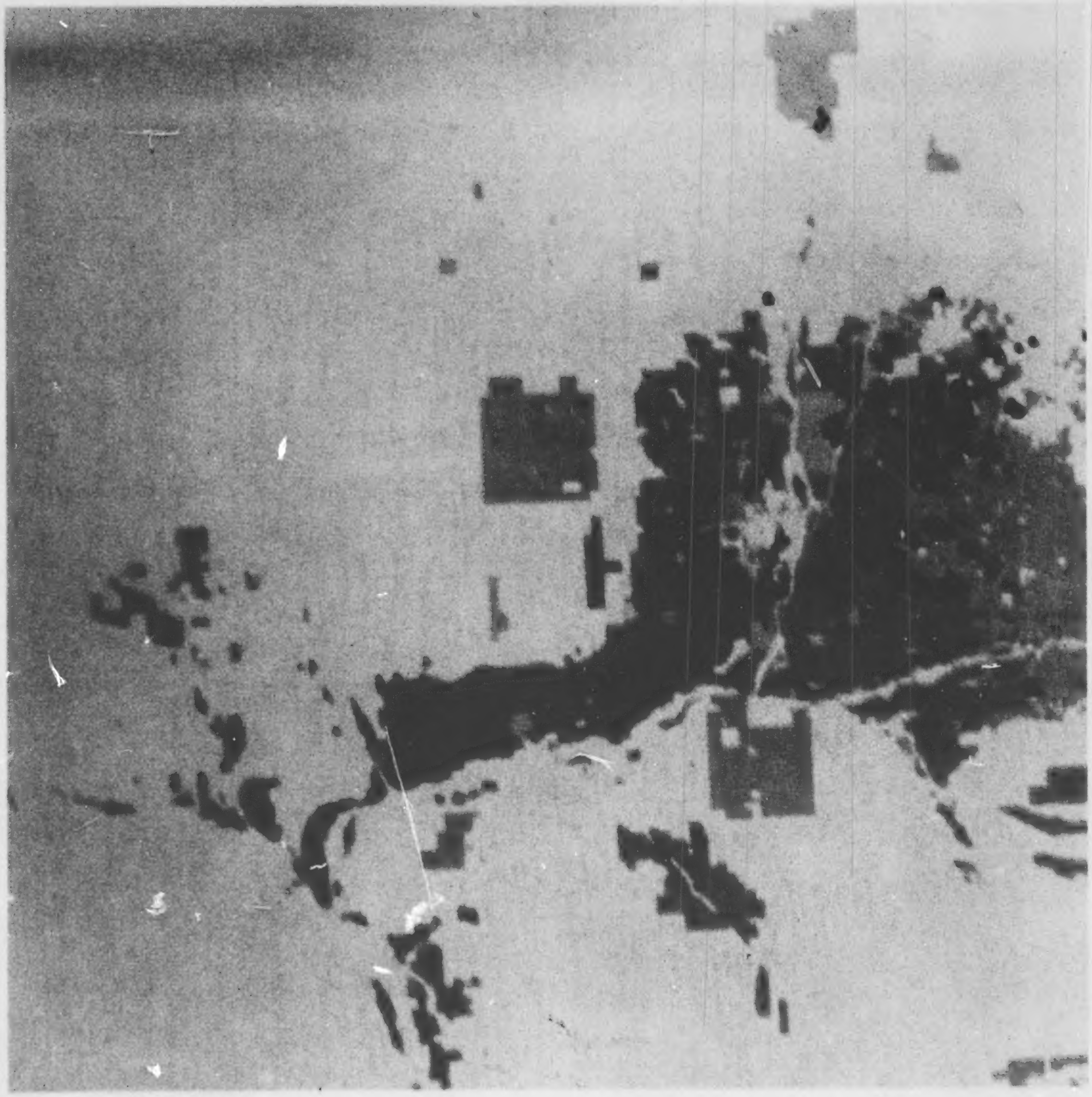
LEGEND

URBAN ■

CROPLAND ■

WATER ■

20. Legend for the maps of land use change, Figures 19 and 21.



21. Change in land use detected using ERTS-underflight aerial photography taken in November 1972 in the vicinity of Phoenix. The southernmost 10% of the Phoenix Quadrangle was never covered by the aerial photography. The red change is new residential, the green is cropland, and the blue is surface water.

CHANGE OF LAND USE IN THE PHOENIX QUADRANGLE AS DETECTED FROM ERTS

NOVEMBER 1970 TO MAY 1973

(SQUARE KILOMETER CELLS)

TO

FROM	RESIDENTIAL	CROPLAND	DESERT SHRUB	RESERVOIR
RESIDENTIAL	-	0	0	0
CROPLAND	30	-	0	19
DESERT SHRUB	3	23	-	55
RESERVOIR	0	0	0	-

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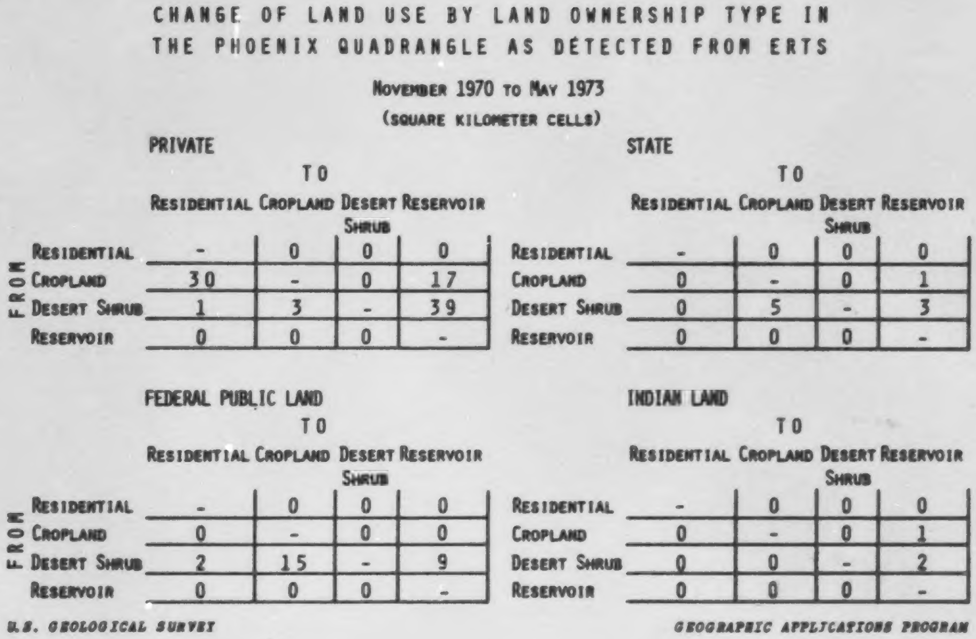
22. Matrix of change found in the Phoenix Quadrangle between 1970 and 1973. Areas are in square kilometers.



CHANGE OF LAND USE BY LAND OWNERSHIP TYPE IN THE PHOENIX QUADRANGLE AS DETECTED FROM ERTS

November 1970 to May 1973

(square kilometer cells)

PRIVATE

FROM \ TO	Residential	Cropland	Desert Shrub	Reservoir
Residential	-	0	0	0
Cropland	30	-	0	17
Desert Shrub	1	3	-	39
Reservoir	0	0	0	-

STATE

FROM \ TO	Residential	Cropland	Desert Shrub	Reservoir
Residential	-	0	0	0
Cropland	0	-	0	1
Desert Shrub	0	5	-	3
Reservoir	0	0	0	-

FEDERAL PUBLIC LAND

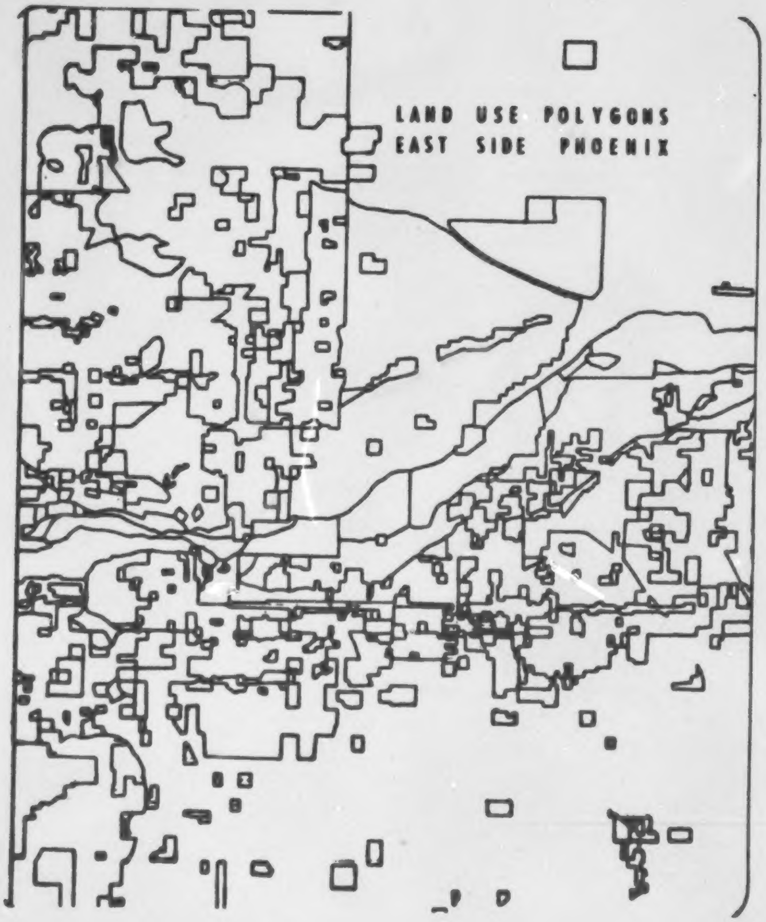
FROM \ TO	Residential	Cropland	Desert Shrub	Reservoir
Residential	-	0	0	0
Cropland	0	-	0	0
Desert Shrub	2	15	-	9
Reservoir	0	0	0	-

INDIAN LAND

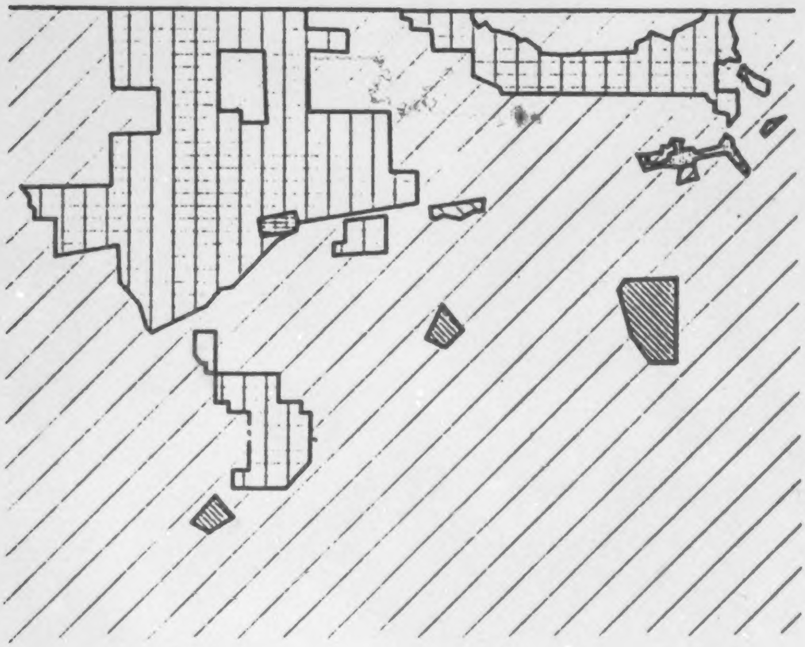
FROM \ TO	Residential	Cropland	Desert Shrub	Reservoir
Residential	-	0	0	0
Cropland	0	-	0	1
Desert Shrub	0	0	-	2
Reservoir	0	0	0	-

U.S. GEOLOGICAL SURVEY *GEOGRAPHIC APPLICATIONS PROGRAM*

23. Changes, presented in Figure 22, broken down by land ownership class.



24. Example of an automated plot (1:120,000) of the land use map of the east half of Phoenix. The computer data bank contains the digitized record of polygon boundaries and the type of land use represented. A capability exists to fill in symbols or cells within the polygons. This is merely a test check on polygon boundary lines. Although this was made from photos, ERTS images could be used to update such a map record.



25. New technique for automated plotting of land use polygons from the computer data bank. Color symbols or cross-hatching are used to indicate land use types. This shows Gila Bend, Arizona.

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PHOENIX

Vocabulary - Define the following terms in detail.

Quadrangle
Cropland
Rangeland
1:250,000
Bands 4, 5, 7
^{2}S

Matrix
Cellular maps
Polygons
ERTS
USGS

Questions - Answer the following inquiries in detail.

1. What application does mapping have for future land use planning?
2. How do you make a computerized map?
3. Discuss in detail the land use classification system of Level I and II categories.
4. Explain the change of land use in Phoenix from 1970 to 1973 including residential, cropland, desert scrub, and reservoirs.
5. How were seasonal changes monitored and what was their application?
6. Explain the change of land use in private, state, Federal, and Indian land from 1970 to 1973 including residential, cropland, desert scrub, and reservoirs.

Discussion Topics

1. Why is extensive land use planning needed by legislators in determining a community's long term needs?
2. How was land-use planning accomplished prior to LANDSAT?

IMPROVED RESOURCE USE DECISIONS AND ACTIONS THROUGH REMOTE SENSING

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Houston, Texas - June 1975
Vol. 1C - Land Use and Marine Resources

ABSTRACT

Michigan State University continues to be engaged in applications of remote sensing to a considerable variety of needs of governmental agencies and private organizations in order to facilitate the operational uses of remote sensing for improving management decisions and actions concerning resource uses. Cumulative experience reveals that operational applications are not all the same and that it is important to distinguish between at least two categories, namely (1) first generation, or direct-action; and (2) second generation or indirect, delayed-action applications. Making this distinction is crucial for many reasons, such as justifying proposed undertakings, guidance for research design, methodolgy requirements, budget allocations, and many others.

From among applications completed during 1974-75, seven case studies are offered in illustration of the many contrasts which can be drawn between first and second generation application studies. These include: (1) multi-agency river basin planning; (2) corridor assessment and route location for highway location together with improvement of county-level planning decisions; (3) improving timber management practices; (4) enforcement of new state statutes; (5) county-wide open space preservation; (6) land value reappraisal relative to property tax equalization; and (7) optimizing agri-business processing plant locations.

INTRODUCTION

Governmental agencies in Michigan at the state, regional and local levels are presently investigating and selectively implementing findings derived from applications of remote sensing techniques. Similarly, a number of private organizations are experimenting with this technology as a means of performing their missions more effectively. Michigan State University, with support from the Office of University Affairs of the National Aeronautics and Space Administration, has been actively involved in demonstration projects and a variety of technical assistance efforts to facilitate the operational uses of remote sensing for improving the decisions and actions for many of these management needs.

After several years of working with a variety of public and private user-agencies in experimenting with many different kinds of applications, the MSU investigators have developed certain perceptions about operational applications which they believe can be helpful to others. By this presentation, the MSU team wishes to offer for examination a summary review of a series of applications as illustrations of how some operational applications of remote sensing technology improved users' performance and improved decisions subsequently made and the effectiveness of actions ultimately taken......all of which steps are important phases in the process of "management". Management is viewed as a continuum within which there are many interwoven, interrelated strands, and two most essential functions of management for the purposes of this essay, are the making of decisions and the subsequent taking of actions.

Experience demonstrates that these phases or functions of management are interrelated to varying degrees; but relative to decisions and actions being influenced by remote sensing techniques, the factor of TIME-DISTANCE between the making of a decision and the taking of an action, together with the relative generality or specificity of information derived from the remote sensing input reveal a number of important distinctions which should be made between certain kinds of applications. Applications are clearly not one general, uncatalogued collection of remote sensing uses. The MSU experiences revealed that it is important to make distinctions at least between what applications will (a) have direct impacts on a given situation with a strong likelihood of generating, in a short interval of time, both decisions and implementing actions; and (b) those applications which will produce results over the long term with probably an appreciable time lag in the intervals before results begin to be displayed. These judgments then led to separating operational applications into two categories:

(1) First generation or direct-action applications.

(2) Second generation, or indirect, delayed-action, multiple-faceted applications.

These two categories of applications are not sharply separable; they do overlap and sometimes conflict. This presentation is intended to show, among other features, for example, how the first generation, direct-action type does not only improve the effectiveness of the action(s) taken in support of decisions made; but provides reliable bases for making the decisions in the first place and shortens the time span between when the decisions are made and actions are taken.

Of the many possible differences between these two generation types, the following are worth noting:

1. For one type (first generation), the application is made for a very specific situation which can be located, identified, and evaluated in a span of weeks or days....... while in the other (second generation), the application is made in response to a considerable breadth of general, not immediately specific, needs; usually requires a long period of time (months, years) to identify and inventory characteristics; and evaluations don't usually lead into immediate decisions, let alone actions. Multiple decisions and actions can flow out of this latter type of application; and sometimes other uses for the derived information develop which had not been anticipated.

2. For one type the situation typically is small in scale, such as a functional site or a localized problem.......while in the other type the situation is usually large in territorial magnitute and/or ramifications, such as a river basin or metropolitan region.

3. For one type, the time intervals between initiation of investigation, completion of all research evaluation and reporting, making of decisions, and taking actions are characteristically brief. For the other,

these intervals are much longer possibly stretching into multiple months or years.

4. For one, the remote sensing application makes possible the improvement of the quality and effectiveness of actions taken which lead from decisions previously made; but quite different...... such as the passing of an ordinance which establishes certain standards and/or prohibits certain kinds of practices. Remote sensing information may reveal violations of the ordinance thereby providing clear evidence for enforcing its provisions. Under the other type of application (second generation) remote sensing can provide a means for the mere purpose of making decisions more wisely and effectively, and may never lead to actions directly traceable to the original information base.

   Most importantly, the data derived from this type can be useful for other research operations, not necessarily related directly, by being combinable with other kinds of environmental and/or social information.

5. For one, all steps taken are unprecedented or innovative, calling for experimental routines to develop prototypes and indicators. For the other, after research design is tested and adjusted, much of the work becomes repetitive.

These several distinctions are crucial because they permit differentiation between two different needs that user-groups have, each requiring different information inputs which call for different methodologies and procedures for the research design, budget determination and commitments, personnel logistics, tabulation and presentation formats and analysis routines, data storage and retrieval. The time dimensions can also be a governing factor as to feasibility and what routines need to be utilized.

As noted previously, these perceptions have emerged after many operational application experiences which were varied..... in type of situation, problem, etc.; in scope and magnitude of study; as to user-agency type; as to use of derived information; as to length of time intervals and overall time required to complete the mission.

From among those completed during the 1974-75 year, seven case studies are offered in illustration of the many contrasts which can be drawn between first and second generation studies. These selections include: (1) multi-agency river basin planning; (2) corridor assessment for highway routing and improvement of county-level planning decisions; (3) developing effective timber management practices in areas of scattered forest holdings; (4) enforcement of a recently enacted State of Michigan Soil Erosion and Sedimentation Control Act (P.A. 347-1972); (5) measures and procedures for local implementation of the new State of Michigan Farmland and Open Space Preservation Act (P.A. 116-1974); (6) appraisal standards and applications for land value reassessment relating to property taxes; and (7) optimizing agribusiness processing plant locations.

METHODOLOGY

To make such operational applications possible, a basic methodology has to be structured as a prefatory step. Common to any applications research dealing with land features is the matter of following some system for classifying the characteristics of whatever features are to be considered. In Michigan, the Office of Land Use of the State Department of Natural Resources (OLU-DNR) formed a Classification and Referencing Advisory Committee which, in the spring of 1974, completed a working draft of a land cover/use classification system designed to be applicable to any part or all of the State's terrain. The system was especially structured to use both high altitude and spacecraft-generated IMAGERY.

At the completion of the first edition of its classification system, the Committee recommended that it be field tested at the regional and local level and then be appropriately revised as needed corrections became evident. Such field testing was judged to be indispensable before distribution was made of the classification system for any general or particular use.

The Michigan State University Program had five of its investigators serving on the Classification and Referencing Advisory Committee, and because of the demonstrated interest and capabilities of the MSU staff in operational uses of remote sensing, the Program was requested to participate in the testing of operations, working jointly with the West Michigan Regional Planning Commission staff (WMRPC - a nine county official region headquartered in Grand Rapids) and with the State DNR Office of Land Use. In this joint effort the MSU team tested the classification system in a multi-level inventory of two counties and four townships in the WMRPC region.

The interpretation was accomplished using high altitude COLOR INFRARED photography (1:120,000 and 1:60,000) and medium altitude black and white photography (1:40,000). Information obtained after interpretation was recorded for four hectare grid cells on computer coding forms which are compatible with the WMRPC computer-managed information system.

As a result of the findings of the combined field test and review activities, several changes were made to the system, such as sharpening or broadening definitions, dropping some categories and adding others, etc. The intent of the overall effort was to develop a classification system which could serve the land cover/use inventory purposes throughout Michigan with as much versatility as possible. The MSU Program utilization experiences are repeatedly confirming the effectiveness of this system in a number of different features of operational applications. For example, many of the case studies about to be presented demonstrated that reliable comparability could be made between disparate applications by use of this classification system.

CASE STUDIES

The following presentation expands upon each of these seven case studies by providing summary descriptions of the principal features. (See Figure 1 for locations).

Case Study ①

Second Generation Type Application

Kalamazoo River Basin Study.- Land development in Michigan watersheds over the past two to three decades has generated an aggregate demand for uses of land and water for different purposes which has increased substantially the pressures on water and related land resources. This situation has intensified the need for workable and forceful policies which can monitor and manage resources so that further environmental degradation can be averted.

To achieve any progress in this effort reliable, useful, up-to-date information is needed. With so many different kinds of agencies playing a crucial role in conservation and monitoring processes, coordination is indispensable. In order to facilitate coordinated conservation measures, watershed planning agencies require the very best, latest, and in-depth information, especially information on current characteristics, land cover, and land use. In the past, resource information has been obtained principally via the "Conservation Needs Inventory" and from similar and related programs.

All of these utilize an on-the-ground sampling methodology which are not only questionable as to accuracy; but do not meet the need for information on the spatial distribution of categories within a survey area. This situation has led resource planners and policy makers to search for more accurate, more complete, and less extrapolative data acquisition procedures.

The Kalamazoo River Basin, located in Southwest Michigan, is currently the subject of a three year resource planning effort designed to culminate in a series of action programs for the sensible use of land and water resources in the multi-county area. The principal units behind this effort are the River Basin Planning Group (RBPG) of the Soil Conservation Service, U.S. Department of Agriculture (SCS + USDA), the Economic Research Service, the U.S. Forest Service, and the Michigan Water Resources Commission.

Working in collaboration, these several agencies formed a Technical Committee which has been the action arm for the group. The Technical Committee prepared an extensive outline of information needs and research strategies which strongly emphasized the fundamental need for a detailed land cover inventory. The land cover inventory was considered as the major component of basic information which made possible such studies as analysis of flood plain problems, sediment control, identification of wildlife habitats, recreational planning,agricultural crop production and forestry.

At the request of the River Basin Collaborative, the Michigan State University Remote Sensing Research Program was requested to conduct a land cover inventory for the entire 8,600 square kilometer Kalamazoo Basin. The inventory was completed in two stages. The first involved a demonstration of the scope and efficiency of available RB-57 color infrared imagery (CIR) in providing land characteristics data required by the RBPG for the component 2,800 square kilometer Upper Kalamazoo Watershed. A comparative cost analysis framework used to evaluate different methods of interpretation and image types possible in completing the task was also part of the overall mission.

Upon the successful completion of these tasks, the second stage of inventory was undertaken on a contractual basis. This consisted of inventorying land cover characteristics for the substantial remainder of the Kalamazoo watershed.....the 5,800 square kilometers of the Lower Basin. These data were derived from commercially flown and processed color infrared imagery at 1:31,680, with all costs shared by the participating agencies. At the same time the counties within the watershed participated with supplemental funding to have additional territory photographed for those remaining segments of each county that were outside the boundaries of the watershed configuration.

The data collection for this Lower Basin utilized some notable differences in methods, in contrast to those employed for the first stage, i.e., the Upper Basin, namely: (1) commercially flown and processed CIR imagery was used; (2) the user-agencies paid for the imagery; (3) the classification system was revised; (4) inventory data were recorded on U.S. Geological Survey topographic quadrangle base maps; and (5) land use area distribution was calculated in terms of soil associations.

A summary of the inventory characteristics for the combined Upper and Lower Kalamazoo Basins project is displayed on Table I. An illustration of the method of data portrayal on maps is displayed by one example in Figure 2.

Uses of the Kalamazoo Basin Information. - As previously noted, this category of application, the "second generation", or "indirect, delayed-action" type implies long term and, very likely, indirect uses for the derived information to serve as intelligence for the planning and management of the lands and waters of the river basin system.

Already information developed for the Upper Basin (completed in 1974) is being utilized. As reported in an earlier paper of the MSU program in March 1974:

> Several user agencies have found applications for the information obtained in the Upper Kalamazoo Watershed pilot study. The U.S. Soil Conservation Service is applying the study data to analyze flood plains, sediment problem areas, land use, and agricultural water use and pollution. The SCS is also making use of the data in conjunction with the Michigan Department of Natural Resources (DNR) in an examination of fish and wildlife habitats, and area recreational developments. The SCS also plans to use the data in coordinated studies with the Natural River Section of the DNR to analyze natural and scenic river and unique land areas, and in environmental and esthetic quality planning. This agency is also utilizing the study data for defining various activities on land that have been designated as prime agricultural land, and also for determining erosion rates for particular soil groups on specific land uses. Finally, the SCS is cooperating with the Economic Research Service of the USDA in updating and validating the Conservation Needs Inventory.
>
> The U.S. Forest Service is using the inventory data in several analyses. The forest type and acreage data contained in the inventory are being correlated with soils information to determine productivity estimates of forest resources in the Upper Kalamazoo Watershed.
>
> The Forest Service is also using the study data to compile COEFFICIENT INDICES which represent qualitative evaluations of multiple uses of a mixture of resources in a given area. The coefficient indices will assist in determining management strategies for the optimum multiple use of resources in the watershed. This agency is also using the data in specific studies designed to analyze forested areas near urban concentrations to determine if they should be preserved.
>
> In addition to use by federal and state agencies, county planning commissions will also use the data to update and validate land cover and use information in their counties. ("Resource Inventory for Multi Agency Watershed Planning", W.H. Enslin, B. Richason III and M.J. Bennett. In Remote Sensing of Earth Resources Conference, Volume III, pp. 653-670. The University of Tennessee Space Institute, Tullahoma, Tennessee, March, 1974).

For a second generation operational application, these are quite an extensive and varied catalog of early uses. Such prompt application of derived information suggests a long term unfulfilled need for solid, timely, relevant comparative intelligence on land and water characteristics developed on a unified, regional scale.

By completing this dual-basin study, an accurate, cost-efficient, general inventory of land use has been generated which will provide the basis for many possible series of decisions in several spheres. In time some of the decisions will be translated into actions; but it is conceivable that other information needs may be required for some actions to be effectively implemented.

Case Study ②
Second Generation Type Application

Grand Traverse County Special Environments Inventory. This study was a combination of a general land cover inventory and a special environments analysis conducted in collaboration with a group of public agencies. Grand Traverse County, located in the northwest corner of Michigan's Lower Peninsula, urgently needed a network of land and other resource information for multiple purposes. At the request of the Grand Traverse Bay Regional Planning Commission (GTBRPC), the Michigan State University Remote Sensing Program joined in the collaborative endeavors of the County Planning Commission, the Michigan Department of State Highways and Transportation, and the Office of Land Use within the Michigan Department of Natural Resources (DNR) in developing a general 24 category land cover inventory together with the identification and "flagging" of a series of special environments. This dual final product provided a wider scope and capability than was required in the Kalamazoo Basin project.

The special environments classification consisted of 34 special features which provide information relative to prime agicultural lands, wetlands, steep slopes, forested areas, critical soil conditions, and areas of prominent social values, including: (1) developed, commercial, residential and industrial areas, (2) scenic areas, (3) historic areas, (4) unique wildlife areas, and (5) precious wilderness situations. A summary of the inventory characteristics for the Grand Traverse Project is given in Table II.

The inventory data were derived from 1:36,000 color infrared imagery using a four HECTARE grid and were recorded on specially-designed computer coding forms. These forms were constructed so that up to six land cover and seven special environment codes could be recorded for each four hectare cell. With the raw data in this form, a specific locational indicator for each cell was assigned which then offered the possibility of analysis, evaluation and presentation of the generated information by computer methods. Real world constraints and priority weightings can thereby be established as operating rules for information retrieval by which means information can be made accessible and useful for a variety of disparate uses.

One display technique which has been used is a plotter routine which depicts the inventory data through a combination of different designs and color combinations (see Figure 3). In addition, a sorting process can be used to plot only areas with selected combinations of land uses and special features and, possibly later, soils and topographic conditions. In addition to evaluation of socio-cultural parameters of intensive land use conditions, this procedure facilitates land suitability analyses from a physical characteristics standpoint.

Uses of Grand Traverse County Information. Immediately upon completion of the inventories, the data were put to use as a resource base for County planning decisions and continue to serve as a framework for local government participation in highway corridor evaluation and selection. The GTBRPC is using the data to locate the best future growth areas for residential, commercial, and industrial land uses without causing an adverse impact on sensitive environmental areas. For example, the optimum site location for a potential industrial park site was derived by identifying those cells which met the required site criteria of isolation from residential areas, adequate transportation facilities, sufficient contiguous areas for expansion, etc. In addition to these kinds of uses, the inventory information is being applied to locate optimal low environmental impact highway corridors, using weighted values for each land use according to specific geographical areas, primarily the unincorporated territories of townships.

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The land cover inventory and particularly the special environments identifications allow a tremendous variety of corridor options to be derived and made available for comprehensive and coherent local discussion and evaluation..... indispensable processes for facilitating improved decisions for identification and selection of an optimum high corridor. At the State level, the Department of State Highways and Transportation is closely monitoring the utility of special environments intelligence. If experimental applications can demonstrate that this additional method fulfills an adequate function in assisting with highway corridor selection, the procedure can become a required element for future corridor studies.

Although the time-distance interval between decision and action is much less than in the Kalamazoo Basin study, this Grand Traverse endeavor is still a good example of the second generation operational application. To illustrate, data were made available to the Grand Traverse Bay Regional Planning Commission in January 1975 whereby that body was provided with land cover information on which to base planning decisions. A number of decisions were rather promptly made possible. An alternate site for a new industrial plant was derived on the basis of the information provided by the dual inventory. The location and construction of a major new highway, including the selection of an optimum corridor and the location of the specific right-of-way within the expanse of the corridor were made with the fullest possible bases of reliable and up-to-date information, and decisions were able to be made within a comprehensive framework. The Regional Planning Commission is busy making decisions daily as to development configurations with local units of governments which are rapidly developing local/comprehensive development plans. Now that a regional land cover and special environments information system are operational, it will be only a matter of routine functions to keep such a system updated and expanded upon as time advances. This Grand Traverse situation is one which offers encouraging confirmation of the thesis that more competent, effective, and broadly-based decisions and actions will emerge if the informational base is adequate.

Case Study ③

First and Second Generation Type Application

Mason County Forest Inventory. - Timber management, harvesting, and marketing comprise the second largest component of the economic base of Mason County, Michigan. Profits, salaries, tax revenues, and other income are derived substantially from wood-based industries in the County. The viability of this economy is seriously handicapped by the largely fragmented holdings of privately-owned forested lands. Over 80 percent of the forest land in Mason County is privately owned, ownership patterns ranging from very small to moderate-sized holdings; but the small tracts are the most common. The interweaving of national and state forest tracts amidst the private lands only further complicates the management, survey and evaluation of timber stands. Another complicating factor is the great variation in the marketable condition and quality of existing individual stands.

One serious aggregate resultant of the operation of these many deterrents and obstacles is the creation of a pseudo-shortage of marketable timber; whereas, in actuality, Mason County is rich in mature timber resources.

The logistics of wood processing industries require a minimum tributary supply of timber within economic haul limits to sustain a profitable mill facility. Production industries are forced to curtail operations of existing mills when the supply of raw materials is below pre-determined economic production-handling volumes. Consideration of expanding existing mill facilities or building new ones is out of the question in the face of any category of shortage.

Mason County is in the potential position of losing its wood-processing industries and thereby its at-hand market facility. Unless ways can be found to identify, manage, and bring to market the forest resources of the area, the County community can foresee the possibility of having the mill abandoned. At present the forest raw material supplies are indeterminate, widely fragmented, dispersed, and in a condition of pseudo-shortage. In the face of such a contradiction, officials in public agencies and private timber industries turned to remote sensing as a possible means to solving a serious problem.

Through the intervention of the West Michigan Regional Planning Commission, the Michigan State Program was asked to work with the local Soil Conservation District officials in furthering the implementation of an existing program for developing effective timber management and wood harvesting programs under the rubric, "Operation Woodchuck."

Uses of the Mason County Forest Inventory. To satisfy a need for information on the location and condition of forest resources, color infrared photography at scales ranging from 1:36,000 to 1:120,000 were used to classify the forests into six species groups, three stocking levels, and three maturity classes within a minimum type size of four hectares. Figure 4 represents one of the forest cover type maps prepared for the Mason County project.

The forest resource maps are being used by the Mason-Lake Soil Conservation District, by the West Michigan Regional Planning Commission, and by the timber processing industries in that area. Uses have already begun which include the development of effective timber management and programming of timber harvesting for the coming years. The representatives from industry are reporting gratifying results in identifying and locating various grades of timber all within reasonable marketing parameters.

Initially this forest inventory application was conceived as a second generation operational application. Forest resource data were required for an information system being developed by the West Michigan Regional Planning Commission. The system was intended to form a basis for a range of local resource development and management programs. Out of this larger systems program emerged the potential for helping resolve the timber marketing problem, and so this potential is being quickly realized. Forest type maps are now allowing the identification of merchantable stands within the county, and so, in its continuing development, the Mason County study has become for the commercial timber interests, a direct-action, quick-turn-around, first generation operational application leading to direct on-land actions by individual land owners and timber marketing firms. The original intent will still be realizable over the future months and years as other resource management processes become structured and operational.

Comment. - The remaining four case studies illustrate first generation operational applications. As will be noted, these will highlight direct decision-action applications. While each application is entirely different from the other three....varying elements in different contexts....they share a common characteristic in serving a specific clear-cut statement of a situation requiring attention, which, when measured and evaluated, leads to making decisions with confidence, and finally, to the taking of definitive actions within a short time-distance interval.

Case Study ④

Farmland and Open Space Preservation - Wayne County, Michigan. - Under a new statute enacted by the Michigan Legislature in 1974, counties have been designated as the agencies responsible for executing the necessary actions in establishing policies and long-range plans for categorizing appropriate lands as desirable permanent open space, and then taking the necessary actions to implement the reservation of such lands. (State of Michigan: Farmland and Open Space Preservation Act P.A. 116, 1974).

Wayne County, Michigan, the home county for the City of Detroit, was the first in the State to initiate implementation of this Act. There were no precedents or guidelines for this kind of development strategy; so considerable consultation and experimentation was essential. When invited by the Wayne County Planning Commission (WCPC) to contribute the potential capabilities of remote sensing to this study, the MSU Program first loaned RB-57 color infrared imagery to the Planning Commission staff, then developed, in collaboration, a land classification system, provided extensive training sessions for Planning Commission personnel, and continued to contribute technical inputs, such as interpretation of imagery. With such assistance, the staff of the WCPC developed an updated inventory of land use for the undeveloped portions of the County. This survey showed, surprisingly, that this very urban County of Wayne has 20 percent (33,381 hectares) of its land still in agricultural uses and other unimproved open space. About one half of this area (16,000 hectares) is currently inactive and unimproved - producing no economic return.

In a policy format, the County Planning Commission declared intent to seek the establishment of a pattern of lands to be reserved as permanent open space. The distribution and location of the ultimate land reservations were to be derived from the future growth configurations emanating from the previously drafted County "development strategies." When these determinations were eventually drawn up, a series of public hearings were conducted all around the County to inform residents and officials of the intent of the program, what benefits could accrue, and how implementation would occur. In concluding this analysis phase, the Planning Commission committed the County to reserving a definite number of hectares in accordance with a determined, designed physical configuration.

The new Farmland and Open Space Act provides for implementation by authorizing the execution of contracts with owners of designated open space lands whereby the owner yields development rights and/or easements to the County. In return, the owner receives property tax relief and freedom from special assessments for improvements of no benefit to his land uses. This process insures that a given property will remain in an agricultural or open space use for a period of 10 years or more.

To be fully implemented, however, the zoning ordinance of any local government unit agreeing to participate in this program must be amended to incorporate provisions which will accommodate the special features of land reservation provided for in this State Act. In addition, the local zoning ordinance must also incorporate revised land use district configurations to mesh with the County development strategies plan. The local unit must also formally express concurrence with the policies of the County.

In this case of Wayne County, the optimum location and extent of these open space areas were determined through the use of remote sensing imagery and related techniques. Interpreting soil characteristics, land cover and slope, alternative patterns of open space were constructed. These kinds of information were derived from NASA high altitude (RB-57) color INFRARED PHOTOGRAPHY. By use of appropriate interpretation, it was feasible to interpret land characteristics of substantial areas in a very short time. The whole County was interpreted and plotted in a matter of weeks. The processes of review and evaluation, via public meetings and deliberations by governmental officials required, however, considerably more time.

To date, five townships in Wayne County have progressively decided to join in this open space preservation program. At the time of preparing this paper, several other local units have various versions of land reservations under consideration. This effort actually has produced other benefits in addition to retaining agricultural productivity of farmlands and the aesthetic values of holding substantial lands in open space condition. The Wayne County study has provided a prototype procedure that has been tested, refined, and restructured in the Wayne County application. The MSU Program is arranging to work with other Michigan Counties to assist in further implementations of Act 116.

Effectuation of policies and programs like the Michigan Farmland and Open Space Act will have substantial impact on the character and nature of human settlement over the next decades; for it will be by means of such concepts that the continuing accretions of undifferentiated urban sprawl that has characterized urban growth over the past fifty years will be arrested and hopefully diverted into more livable and effective patterns.

While long range implications of this kind of legislation are very important, successful implementation will depend to a large degree on an information base which can be derived in a short interval of time. The one major-and most promising and reliable-means for securing the needed information is that of remote sensing technology. As the versatile capabilities of remote sensing become better known, more and faster progress toward essential societal and environmental reform can emerge as technical capabilities make innovative concepts appear achievable.

Case Study ⑤

Soil and Sedimentation Control - Antrim County, Michigan. - The Antrim County Planning Department (ACPD) has used remote sensing in an even more direct manner to implement the State of Michigan Soil and Sedimentation Control Act (P.A. 347, 1972). Color infrared photography provided an expeditious, legally acceptable means for both evaluating site construction plans required for earth-change operations and for detecting potential violations of codes and ordinances. Two examples of situations on Torch Lake in Antrim County illustrate this capability of remote sensing for helping evaluate possible violations and earth change requests.

The Act requires that a site plan be approved and an "Earth Change" permit be obtained for any operation which will change the configuration of the ground form....i.e., an "earth change"....if that activity is located within 500 feet of a lake or stream. A citizen complaint received by the ACPD in August 1974 suggested a possible violation (see Figure 5). The alleged violator was of the opinion that the road construction underway was 600 feet from the nearest point on Torch Lake (the distance A-C on Figure 5). Using the photography, the ACPD determined that in fact the site was 365 feet from the Lake (the distance A-B on Figure 5). A stop-work order was issued to the violator based on the data derived by photo interpretative techniques. The order was initially challenged and a ground survey requested; but both the violator's attorney and the County Prosecuting Attorney agreed that the photographic evidence was legally acceptable, and the order stood.

In another case, also in Antrim County, a site plan and request for an Earth Change permit was submitted for the construction of a groin wall on Torch Lake. The proposed wall (approximately 24 feet long) would be at the north of the owner's property line on the northwest end of Torch Lake (Point A, Figure 6). There is an existing groin wall (Point B, Figure 6) that would be removed when the new wall was constructed. In evaluating the site plan, the ACPD assessed the potential effects of the 24-foot groin wall on the present lake erosion and sedimentation patterns through an analysis of these patterns depicted on 1973 color infrared imagery. A northeasterly and southern lake current (see points D and C, Figure 6) converge at this general area. The resultant heavy turbulence zone creates a sucking and cutting action which promotes shoreline erosion immediately to the north of the present groin wall. The Department decided that a 24-foot long wall at the proposed location would intensify this erosive action, thus an Earth Change permit was denied. Extending tangents from the shoreline on both sides determined the location and maximum length (12 feet) of a groin wall that the Planning Department was prepared to allow (Figure 7).

Both examples show that remote sensing technology can provide a timely, accurate, and in some cases, the only comprehensive means to evaluate legitimate Earth Change permit requests and also offer an effective and legally sound method of enforcing the Soil Erosion and Sedimentation Control Act.

Case Study ⑥

Land Value Appraisal - Charlevoix County, Michigan. - The Charlevoix County Equalization Department is using color infrared photography to reassess more accurately land values, particularly for remote and isolated properties. Beaver Island, located 12 miles off the coast into Lake Michigan provided the county with an especially difficult assessment problem. Large scale black-and-white photography was available for the island; but this imagery did not permit adequate identification of swamp and higher ground which are the two basic criteria for property evaluation in such terrain. Moreover, due to the inaccessibility of the terrain, usual ground inspection methods were deemed unfeasible. Land value appraisal and consequent property taxes levied for the Island, using such limited information as these black-and-white photos, were inevitably approximate and most imprecise. Using rudimentary interpretation and projection techniques, the Equalization Department personnel, with CIR imagery provided by the MSU Program and MSU interpretative assistance, were able to produce a simple land characteristics map of Beaver Island as well as of several other islands in the County. All property valuations for the islands have been reassessed and changed where appropriate on the basis of these mapped data backed up with photographic evidence.

Appraisal of land value is becoming an increasingly complex and detailed process. Color infrared photography used here without sophisticated equipment provided an accurate and time-saving method which facilitated new value appraisal and assessment methods and achievements.

Case Study ⑦

Optimizing Agri-Business Processing Plant Locations. - In the Saginaw Bay area of Michigan, beans, corn and small grains are important crops requiring immediate processing for storage and marketing. For effective operations, it is economically and technically crucial that processing facilities be located within areas of high crop production. In addition, recent increases in both crop acreage and yields have created a need for expanded processing facilities at new sites. In the past, elevator location decisions were a "hit-or-miss" process based mainly on subjective and unscientific procedures and criteria. Crop Reporting Service statistics regularly indicate production totals by counties. However, elevator service areas with a radius of 13 to 16 KILOMETERS, are areas substantially smaller than a county, and many include parts of more than one county. In the absence of data on the spatial distribution of specific crop acreages within each county, processing firms lack adequate information for their locational decisions.

The main criteria for optimizing processing plant and elevator locations are: (1) centrally located in relation to the county's largest crop production area; (2) adequate highway (Class A) accessibility; and (3) railroad accessibility. In the past, this information was acquired from windshield surveys by company personnel. No quantitative acreage evaluations were possible, and only a generally-defined service area could be identified. The business firm would seek an elevator site with adequate accessibility within this generally defined service area.

MSU Remote Sensing Program personnel, in cooperation with one particular large agribusiness firm are investigating the use of satellite and NASA research aircraft imagery to acquire an improved data base for corporate decisions aimed at optimizing the location of future elevator facilities with respect to crop production areas and to the criteria previously enumerated.

In the instance of this case study, the research work is in progress; a completed analysis with consequent decision-action results cannot yet be reported, except that in the fall of 1974 the MSU Program did a pilot study for this firm using whatever imagery was available and fitting in the analysis to meet very limited time constraints (placed on the user by market pressures). The business organization was most gratified with these particular results, and accordingly has concluded arrangements with the MSU Program to continue in 1975 with studies in other areas of the State in order to determine optimum locations for at least three additional processing plants.

Investigations by the MSU Program will be designed to meet these stated needs. For each county selected, four categories of information will be identified:

(1) amount and distribution of tillable land in the county;
(2) highway and railroad accessibility;
(3) identification of the present distribution of beans, corn and small grains;
(4) potential crop productivity based on soil management groups.

The investigators will use Skylab imagery to locate and define broad crop service areas containing intensive cultivated land and good transportation accessibility. In each broad service area the categories of information (previously cited) will be identified and delineated from NASA RB-57 high altitude color infrared photography. The mapped information as well as soils information for these selected areas will be gridded and coded for computer storage and then alternative plant sites will be selected.

For each identified potential site, a routine will calculate total area in each type of agricultural use and will estimate potential crop productivity for assigned service areas. Finally, recommendations for specific sites for the location of new processing plant elevators will be made. It is important to emphasize that during most of these analysis operations, the business firm personnel will be equally involved in the processes except where special technical skills are needed. Through participation, the user will learn more about the features of the business operation, perhaps discern new relationships of dynamics, etc. But, more directly important to the MSU involvement is that another user will have become knowledgeable of the appreciable utility of remote sensing.

SUMMARY AND CONCLUSIONS

The original intent of the remote sensing program at Michigan State University was to experiment with remote sensing technology to determine its usefulness as a means for deriving more complete and reliable information concerning characteristics of land cover and use than conventional methods provide. In addition, factors of economics of time, materials, and costs were important criteria for concomitant evaluation. Finally, it was hypothesized that remote sensing could provide information which had not heretofore been available in either kind or scope which could be derived from new generations or sets of "indicators".

The intended usage for such enriched intelligence was to provide public and private policy/decision makers with much more and greatly improved information upon which to formulate policies, make decisions, and take actions relative to the effective management of land and other natural resources.

The efforts of the Program continue to be directed at this progression of objectives; however, intermediate application experiences have been utilized as means for developing needed knowledge and capabilities for investigators. A series of operational applications, of considerable variety, have been engaged and brought to conclusion which have been most valuable for advancement of wisdom and skills.

One important feature of these applications, or "case studies" was the realization that such endeavors are not all the same, that they are considerably different and have to be selected, designed, and executed by utilizing methods singularly appropriate to each. Repeated endeavors clearly indicate a broad primary classification, namely, those which generate prompt, direct responses in terms of decisions and implementing actions (categorized as "first generation"), and those which produce delayed and indirect reactions over time to the information garnered and generated (categorized as "second generation").

This primary distinction has proven very helpful in evaluating possible new engagements. After the first year or two of working at convincing possible users of the relatively unknown utility of remote sensing, the reverse is occurring, with multiple requests coming unsolicited to the Program for assistance in operational applications. It has become mandatory that selectivity be employed in the situations to which the investigators wish to become committed. Some applications are accepted on a contract basis with the user paying for the routine, repetitive kinds of work; but the majority of engagements selected are those which will allow further testing of methods and producing new competencies - both kinds of benefits are moving the Program closer to its objectives.

The illustrations utilized as "case studies" in this presentation are intended to demonstrate the essential distinctions between first and second generation applications and to share some lessons learned for selecting additional case studies and in the planning-design management and execution. As a final note, however, it is important to note that in all these applications, the user-agency was included as a participant in order to maximize understanding of the processes whereby information and findings are derived, allowing the progressive formulation of tentative decisions, and generating early anticipation of what actions might need to be taken as well as discerning other possible uses for the information. Additionally, the agency personnel were many times more helpful in pointing out the likely non-productivity of moving along certain lines and suggesting more promising directions. As each application experience is completed the investigators realize that new methods and capabilities have emerged and that new, important converts to remote sensing technology have been made.

TABLE 1. KALAMAZOO BASIN INVENTORY CHARACTERISTICS

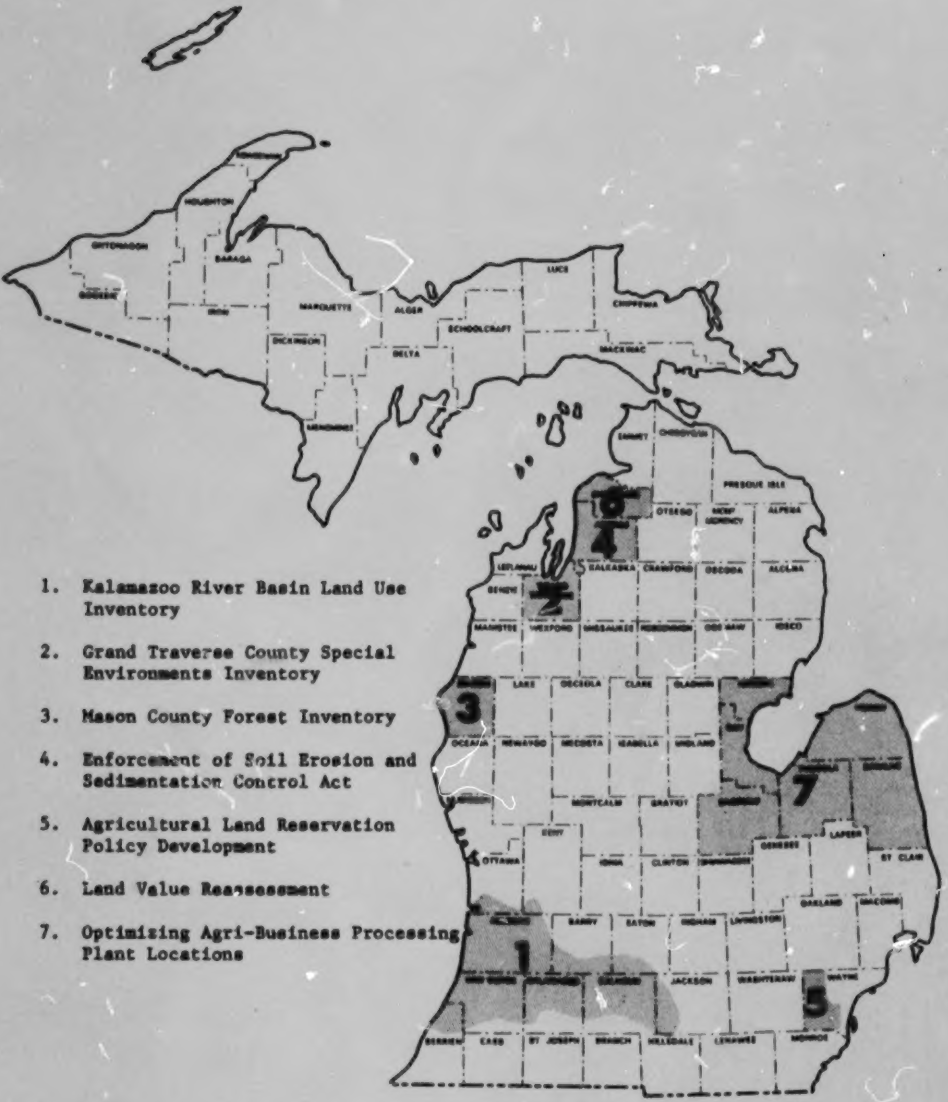
Area	Land Cover/Use Classification	Photography Used	Minimum Type Size	Base Map	Land Use Area Tabulated By[a]
Upper Kalamazoo Basin (2,800 sq.km.)	1. Cropland 2. Orchards 3. Vineyards 4. Small Fruits 5. Pasture, Fallow Land, Forage Crops, Sod & Other 6. Deciduous Forest 7. Coniferous Forest 8. Mixed Forest 9. Brushland 10. Marshland 11. Urban Residential & Commercial 12. Urban Industrial 13. Urban Construction 14. Rural Built-up 15. Water 16. Open Pits 17. Sand Dunes 18. Roadway System	1:60,000 and 1:120,000 Color Infrared	4 ha	County Highway[b] Maps	Township, County, Sub-basin and Basin
Lower Kalamazoo Basin (5,800 sq.km.)	1. Cultivated Cropland 2. Hay, Pasture & Inactive Agriculture 3. Tree Fruits 4. Bush Fruits & Vineyards 5. Ornamental Horticulture 6. Confined Feeding 7. Broadleaved Forest 8. Coniferous Forest 9. Mixed Forest 10. Brush 11. Forested Wetlands 12. Marsh 13. Shrub Swamp 14. Open Water Vegetated 15. Residential 16. Commercial, Services and Institutional 17. Industrial 18. Extractive 19. Transportation 20. Other Urban 21. Water 22. Barren Land	1:31,680 Color Infrared	4 ha	Mylar Copies of U.S.G.S. Topographic Quadrangles	County, Sub-basin, Basin and Soil Association

[a] Area calculations based on a 16 hectare dot grid.

[b] After the completion of the Lower Kalamazoo Inventory the Land Cover/Use delineations for the Upper Kalamazoo Basin were transferred to Mylar copies of U.S.G.S. topographic quadrangles.

TABLE 2. GRAND TRAVERSE COUNTY SPECIAL ENVIRONMENTS INVENTORY CHARACTERISTICS

Code	Land Use	Code	Special Environment (Flags)	Photography Used	Minimum Type Size	Output
11	Residential	01	Roadways	1:36,000 Color Infrared	4 hectare Cell Size	Computer Graphics
12	Commercial, Services, or Institutional	02	Railways			
13	Industrial	03	Airstrips			
14	Extractive	04	Bridge			
15	Transportation Communications and Utilities	05	Powerline			
		06	Gas line			
18	Mixed Urban and Built-Up	07	Oil or Gas Wells (and Storage)			
19	Open and Other Land (outdoor recreation, cemeteries)	08	Confluence of Two Streams			
		09	Mobile Homes			
21	Cropland, Rotation, and Permanent Pasture	11	Ponds			
		12	Great Lakes Shoreline Zone			
22	Orchards, Bush-fruits, Vineyards, Horticulture	13	Inland Lakes Shoreline Zone			
		14	Linear Stream Zones			
23	Confined Feeding Operations	15	Water Access Sites			
29	Other Agricultural Land (farmsteads, green houses, exercise race tracks)	16	Effluent in Lake or Stream			
		17	Impoundment Structures			
		21	Submerged Aquatic Vegetation			
31	Broadleaved Forest	22	Emergent Aquatic Vegetation			
32	Coniferous Forest	31	Forest Plantation			
33	Mixed Forest	32	Forest Fire Area			
41	Forested Wetlands	33	Drowned Forest			
42	Non-forested Wetlands	41	Irregular Topography			
52	Brushland	42	High Bluff or Cliff			
61	Streams and Waterways	43	Low Bluff or Cliff			
62	Lakes	44	Sand Dune			
63	Reservoirs	45	Drumlin, Esker, Kame, Kettles			
92	Beaches	46	Sinkhole			
93	Sand Other than Beaches	47	Islands			
94	Bare Exposed Rock	48	Peninsula			
96	Transitional Areas	50	Terraced			
		61	Cemetery			
		62	Sanitary Landfill			
		63	Junkyard			
		64	Scenic Turnout or Rest Area			


HOUGHTON
ONTONAGON
BARAGA
GOGEBIC
IRON
MARQUETTE
ALGER
LUCE
CHIPPEWA
SCHOOLCRAFT
DICKINSON
DELTA
MACKINAC
MENOMINEE
EMMET
CHEBOYGAN
PRESQUE ISLE
6
OTSEGO
MONTMORENCY
ALPENA
4
LEELANAU
KALKASKA
CRAWFORD
OSCODA
ALCONA
BENZIE
2
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
LAKE
OSCEOLA
CLARE
GLADWIN
3
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
7
MONTCALM
GRATIOT
KENT
LAPEER
GENESEE
OTTAWA
IONIA
CLINTON
ST CLAIR
OAKLAND
MACOMB
BARRY
EATON
INGHAM
LIVINGSTON
1
JACKSON
WASHTENAW
WAYNE
5
BERRIEN
CASS
ST JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE

1. Kalamazoo River Basin Land Use Inventory
2. Grand Traverse County Special Environments Inventory
3. Mason County Forest Inventory
4. Enforcement of Soil Erosion and Sedimentation Control Act
5. Agricultural Land Reservation Policy Development
6. Land Value Reassessment
7. Optimizing Agri-Business Processing Plant Locations

Figure 1. Location of Michigan Application Case Studies.

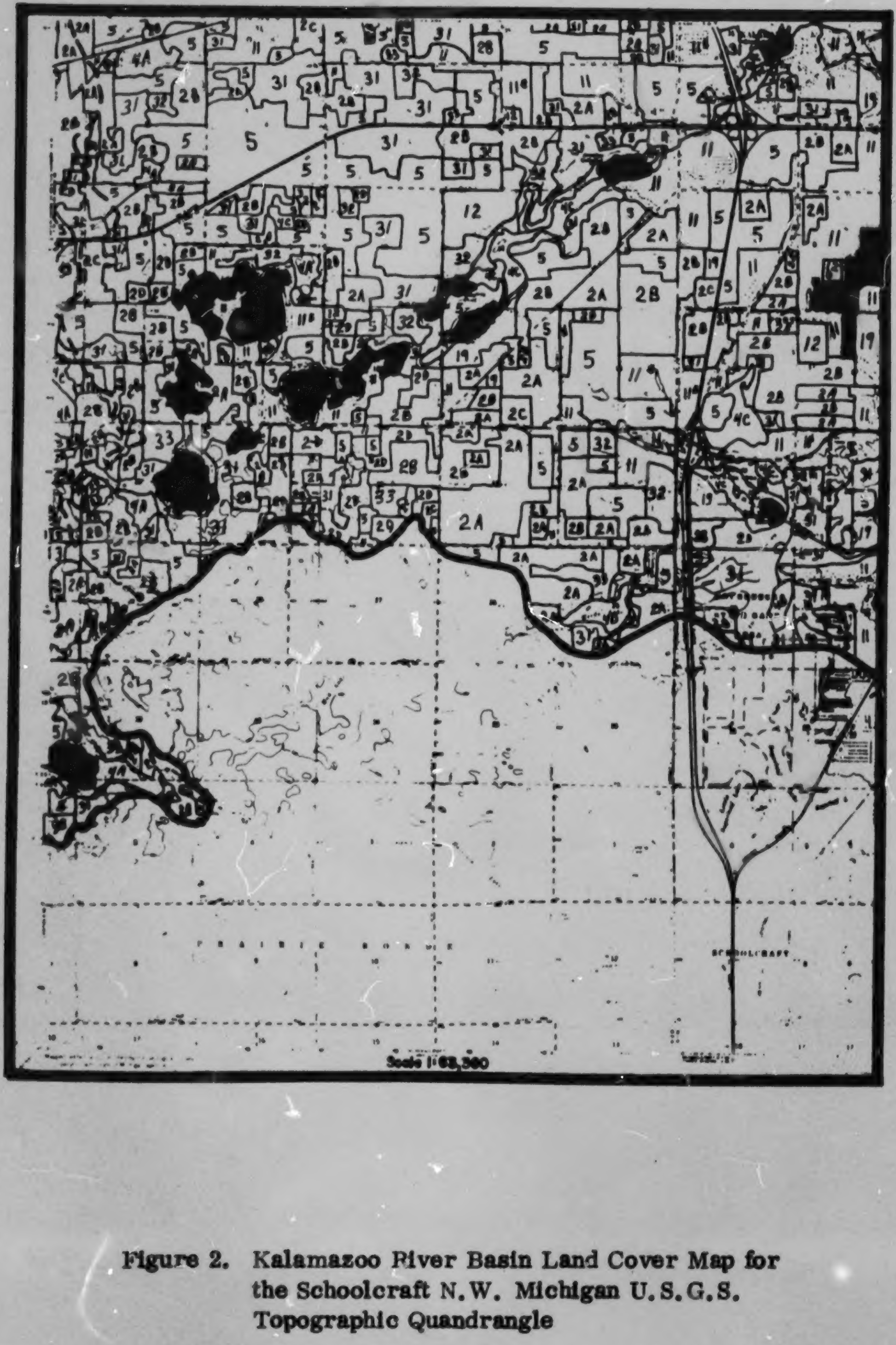

PRAIRIE RONDE
SCHOOLCRAFT
Scale 1:62,500

Figure 2. Kalamazoo River Basin Land Cover Map for the Schoolcraft N.W. Michigan U.S.G.S. Topographic Quandrangle

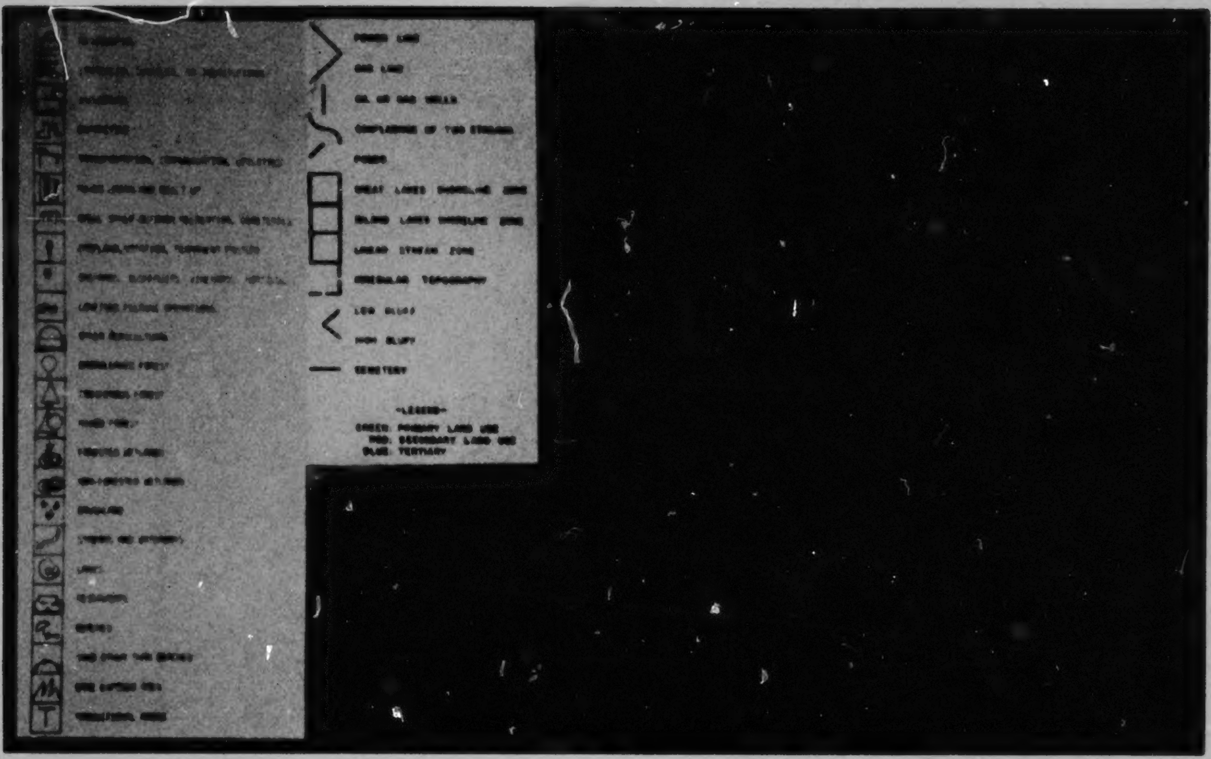

POWER LINE
GAS LINE
OIL OR GAS WELLS
CONFLUENCE OF TWO STREAMS
PONDS
GREAT LAKES SHORELINE ZONE
INLAND LAKES SHORELINE ZONE
LINEAR STREAM ZONE
IRREGULAR TOPOGRAPHY
LOW BLUFF
HIGH BLUFF
CEMETERY
-LEGEND-
GREEN: PRIMARY LAND USE
RED: SECONDARY LAND USE
BLUE: TERTIARY

Figure 3. Land Use and Special Environments Computer Plotter Map Grand Traverse County, Michigan.

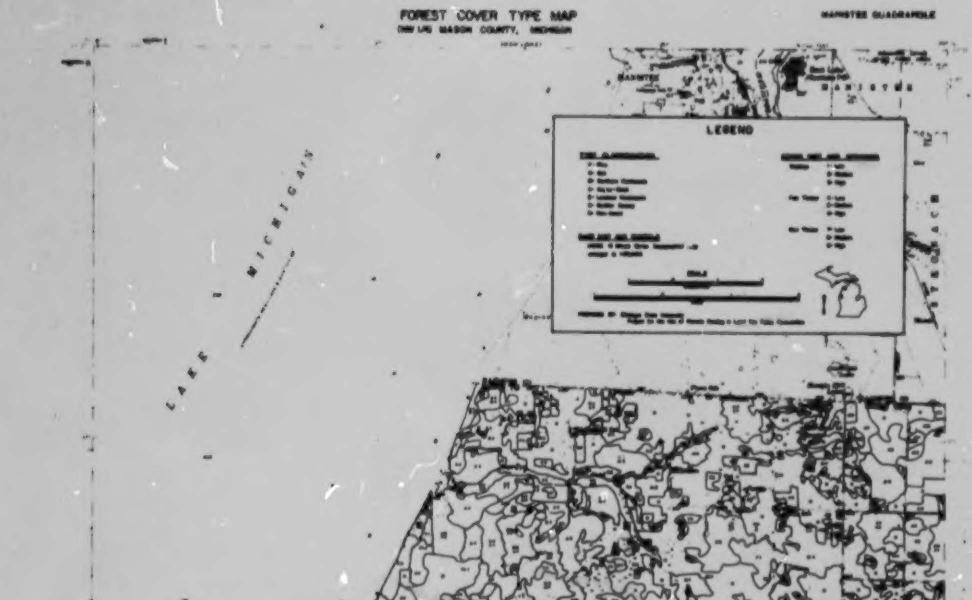

FOREST COVER TYPE MAP
(NW 1/4) MASON COUNTY, MICHIGAN
MANISTEE QUADRANGLE
LEGEND
LAKE MICHIGAN
MANISTEE

Figure 4. Forest Cover Type Map (NW1/4)
Mason County, Michigan.

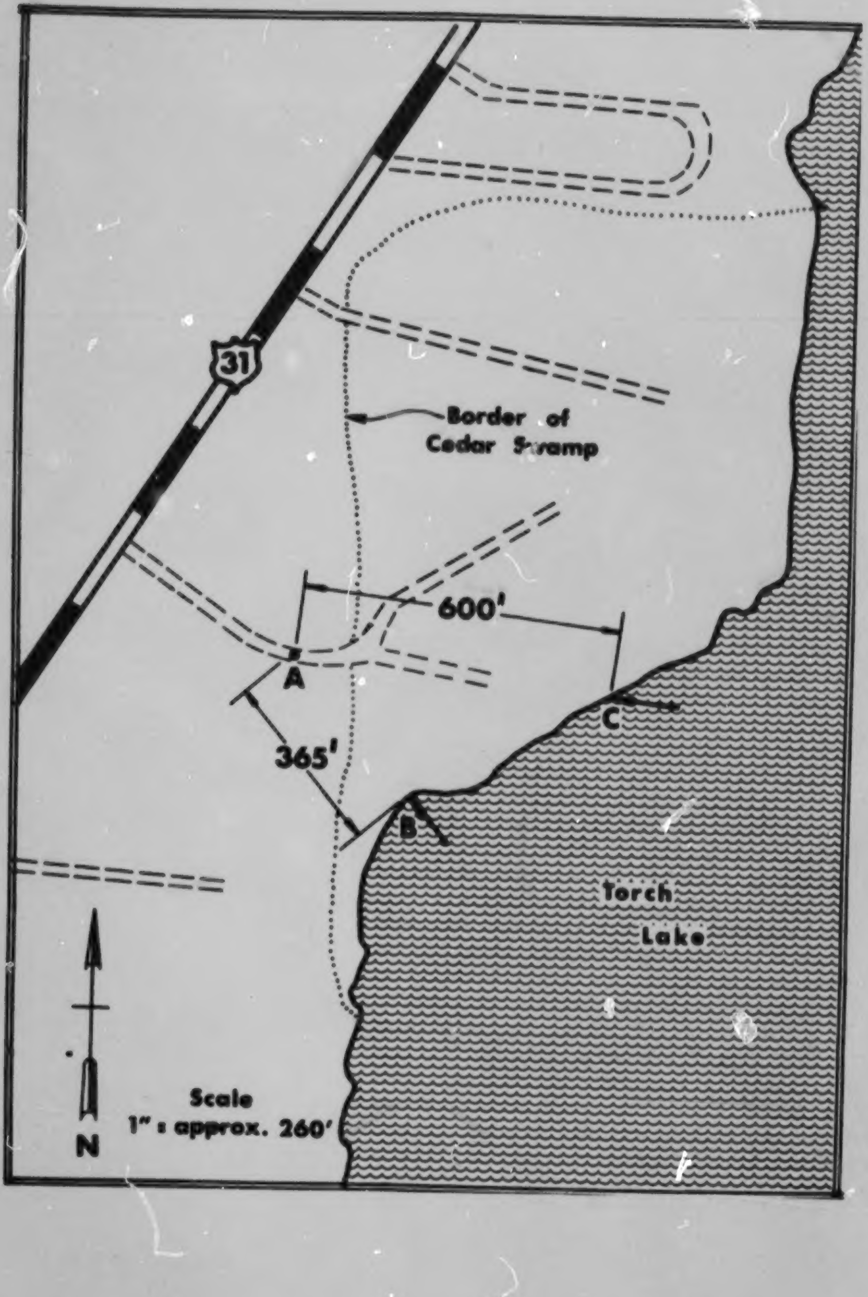

31
Border of Cedar Swamp
600'
A
C
365'
B
Torch Lake
Scale
1" = approx. 260'
N

Figure 5. Site Location in Antrim County, Michigan.

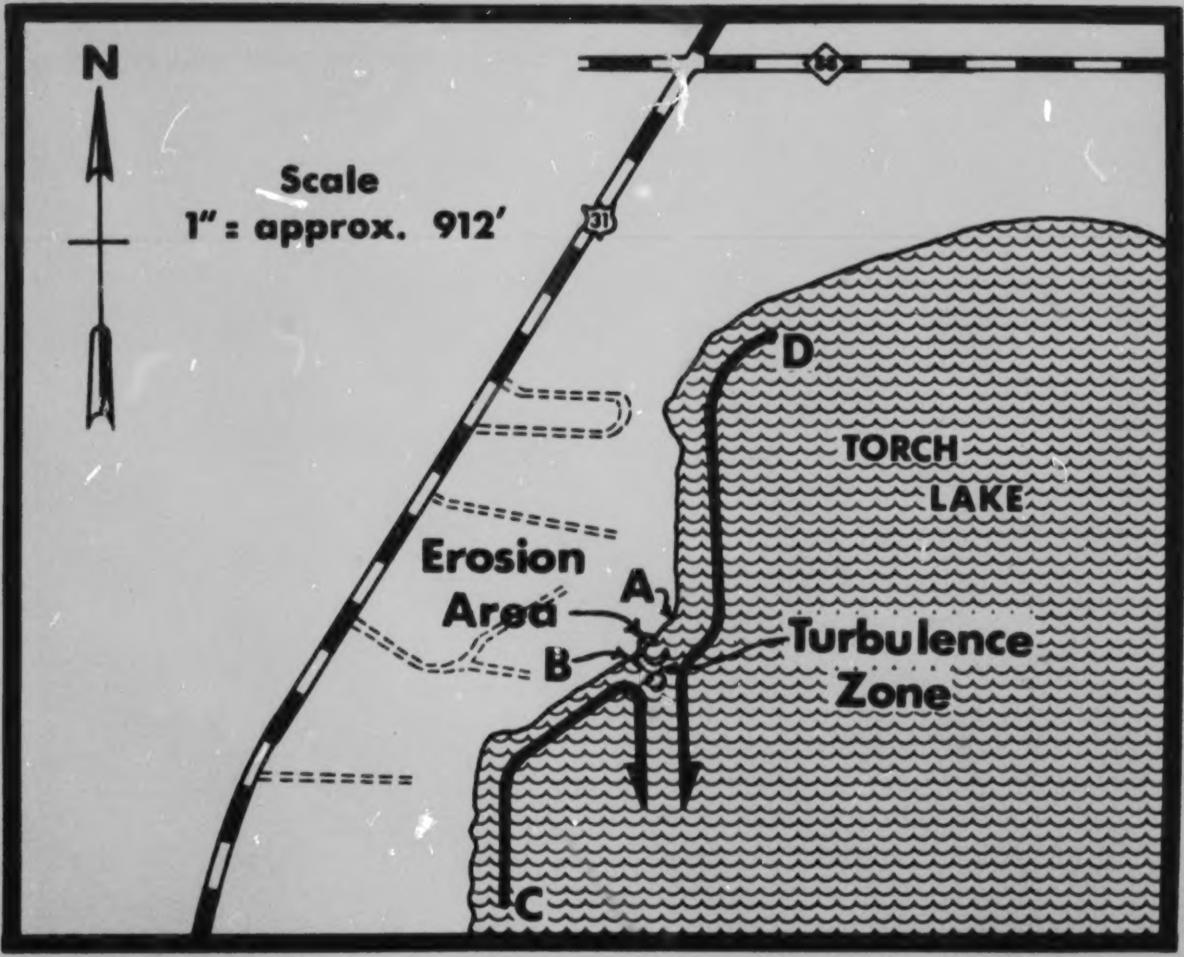

N
Scale
1" = approx. 912'
31
TORCH
LAKE
D
Erosion
Area
A
B
Turbulence
Zone
C

Figure 6. Lake Current Dynamics
Torch Lake, Michigan

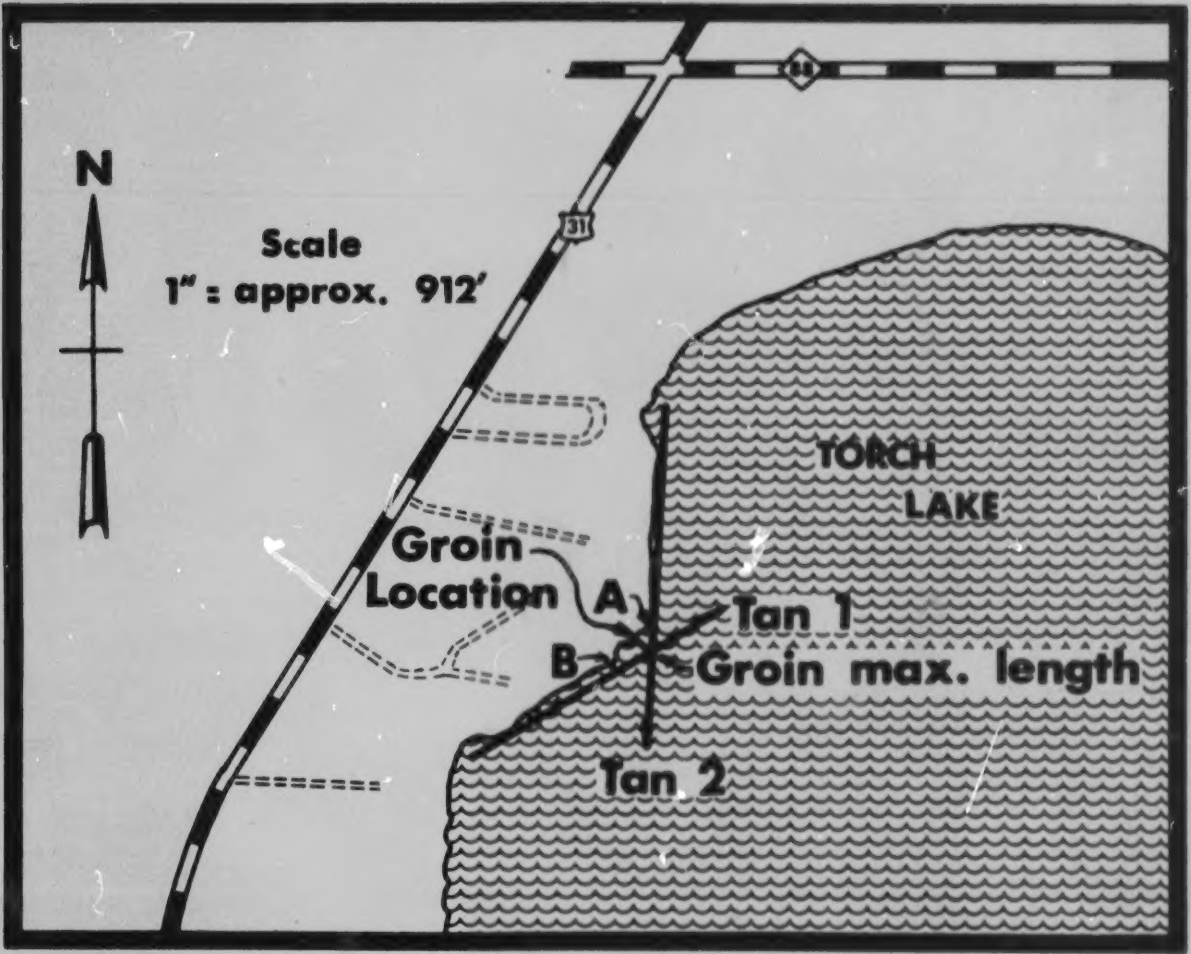

88
31
N
Scale
1" : approx. 912'
TORCH
LAKE
Groin
Location
A
B
Tan 1
Groin max. length
Tan 2

Figure 7. Determination of Groin Location and Maximum Length.

RESOURCE USE DECISIONS

Vocabulary - Define the following terms in detail.

Management
Time-Distance
Direct action
Delayed action

1:40,000
Socio-Cultural
Land cover inventory
Hectares

Questions - Answer the following inquiries in detail.

1. Explain the difference between first and second generation applications as defined in the article.
2. What applications did the overall project have?
3. What was the practical application to Case Study #1?
4. What was the practical application to Case Study #2?
5. What environmental considerations were used in Case Study #7?
6. In Case Study #3, both first and second generation applications were used. Why?
7. What were the uses of the Mason County forest inventory?
8. Why was space preservation important in Case Study #4? Which generation thinking was used and why?
9. In Case Study #5, the major concern was an effective and legally sound method of enforcing Soil Erosion and Sedimentation Control Act. Which generation thinking was used and why?
10. Discuss the application of Case Study #6 to the Tax Assessors Office.
11. Why is it important to optimize the Agri-Business processing plant locations as discussed in Case Study #7? What generation thinking was used?

Discussion Topics

1. Explain decision making and all its variables.
2. What is authority by directive?

PHOTOARCHAEOLOGY

Reconnaissance tests using color, as well as other films, indicate that exploration studies may be reduced from months to hours.

Principal Investigator
CARL H. STRANDBERG
Itek Data Analysis Center

Photogrammetric Engineering
Vol. 33 October 1967

ABSTRACT

In the spring of 1965, the Itek Data Analysis Center conducted a photoarchaeological investigation for the National Park Service. The objectives of this investigation were to determine what type of film, black and white IR, pan-minus-blue, natural color, or color IR, was best suited for detection of archaeological sites along the Missouri River in South Dakota. Coverage was obtained at several scales, and compared with pan-minus-blue scale 1/20,000 USDA photography of the same area. We concluded that natural color and color IR, scale 1/10,000 provided the best interpretation medium, considering the saving in time which these mediums provided.

INTRODUCTION

About 130 years before Columbus landed in the New World, the inhabitants of the village site shown in Figure 1 constructed bastioned fortifications, surrounded by dry moats. This site is located in Lyman County, South Dakota, about 22 miles south of Pierre, the state capital. During this same period in history, my ancestors from southern Sweden constructed similar fortifications in Finland, Western Russia, and other areas then under Swedish control. I bring this point out because this similarity, and other evidence, tend to prove that early Norse explorers visited the New World between the year 1000 AD and at least as late as 1362 A.D. This thesis is controversial; particularly to Italians as evidenced by their reaction to the Vinland Map. I reopen this controversy, however, because many bits of evidence, for which archaeologists have no satisfactory explanation, indicate the possibility of late Viking age Scandinavian penetration into the middle of North America. Mysteries of this kind are examples of the types of problems which may be solved through the proper use of aerial reconnaissance, termed here photoarchaeology, a scientific tool which is made more interesting and effective when color and FALSE COLOR photography are employed.

The full extent of the village site shown in Figure 1, for example, was not known within the Smithsonian Institution's River Basin Archaeological Salvage Program until it was discovered by photoarchaeology in the spring of 1965.

Photoarchaeology is similar in many respects to ground combat tactical photointerpretation. In both instances interpreters are usually searching for small camoflaged installations in rural terrain. The camouflage, in the case of archaeological sites, is generally harder to pierce. It is truly natural camouflage, time emplaced over a span of many years, some hundreds or even thousands. In the case of infantry tactical photointerpretation, detecting critical images under camouflage requires that the proper sensors be used, and that interpreters have knowledge, understanding, and experience. These same requirements exist in photoarchaeology.

THE PROJECT

In the spring of 1965, the Itek Data Analysis Center, under contract to the U.S. National Park Service, undertook a field reconnaissance project in cooperation with the Smithsonian Institution to determine what type of aerial photography, black and white IR, normal pan-minus-blue, natural color, or color infra-red, yielded the best results for photoarchaeology. The critical factors of scale and time of day (because of the impact of sun angle on shadow length) were also evaluated.

TEST AREA

The test area selected is located south of Pierre, South Dakota, along the Missouri River, as shown in Figure 2. This area was selected because much of it is being flooded by dams, and concerted efforts were underway to salvage as many bits of American pre-history as possible before critical sites were covered by mud, silt, and water, and lost for all time. This area has been continuously inhabited for thousands of years. The earlier cultures are classed as Woodland, and are believed to have been largely nomadic. No evidence of permanent villages has been found dating to the Woodland cultures along the Missouri River. The Indian and/or pre-Indian inhabitants seem to have developed an essentially settled agricultural form of culture about the year 1000 AD. Squash, corn, and beans were staple food items, supplemented by meat from buffalo and other native animals. Fish were also probably included in their diets.

The native inhabitants of this area built earth and log houses of three types during the span of years extending from about 1200 AD to the start of the 20th century. These houses have long since collapsed, leaving residual house pits. Some of these houses were accompanied by cache pits for the storage of food as shown in Figure 3.

Village fortifications progressed through three stages. Fortifications which were constructed about the time of the Kensington Rune Stone, of Norse origin and dated 1362 AD were bastioned, as was shown in Figure 1. The bastions were, in my opinion as a bow hunter, too far apart to have allowed mutually supporting enfilade fires using bows of the type used by Plains Indians during the historical period. Scandinavian long bows or crossbows were another matter. Indian villages of this period are termed Hull Focus and sometimes as Middle Mandan sites. Later, when the possibility of European contact was less likely, dry moats were constructed, but bastions were omitted.

The native inhabitants of this area are termed Pre-Arikara. The Arikara was the principal tribe that lived in the area at the time the French explorer Verendrye arrived in 1732. The Mandans also lived in the area. Verendrye reported that the Mandans are taller, and that about 7 per cent of them were blond and blue-eyed, which may offer another clue to the origin of Viking-like fortified villages.

TEST PROCEDURE

A coordinated aerial photographic flight program was conducted, aided by extensive field work. Flight lines over areas of interest on both sides of the Missouri River were set, and comparative aerial photographic coverage was obtained. The area on the west side of the Missouri was quite well known. Two digs were being conducted in the area along the west bank in the spring of 1965. The area along the east bank of the Missouri was scheduled for detailed exploration in the spring of 1966.

PHOTOGRAPHIC OPERATIONS

Vertical photography was obtained along both flight lines from three altitudes: 1,500, 2,500, and 5,000 feet. Four types of film were used: (1) Kodak Infrared Aerographic, type 5424; (2) Kodak Plus-X Aerographic, type 5401; (3) Aerial Anscochrome D-200; and (4) Kodak Ektachrome Infrared Aero, type 8443. A Wratten 25 (red) filter was used to obtain modified infrared. A Wratten K-2 filter was used with the type 5401 film to obtain pan-minus-blue. Zeiss filters equivalent to the Wratten 2B and Wratten 15 were used to obtain the natural and false-color photography, respectively. One flight using the pan-minus-blue combination was made early in the morning when the shadows were long, thereby accentuating positive vegetation marks.

A Zeiss RMKA Camera (six-inch focal-length lens) was used. A portable resolution target was emplaced near the camp where the Itek personnel and the Smithsonian teams lived. Field work included soil sampling for soil color and acidity determination. Low-altitude low-oblique photos were obtained using a Nikon F 35 mm Camera with a Micro-Nikkor lens, and with a Nikon S-2 with a Nikkor-SC 50 mm F/1.4 lens, from a Cessna 172 airplane. Oblique photos were obtained using Kodak SO-243 High-Definition Aerial film with a Wratten 16 filter, and with Kodak Ektachrome Infrared Aero, type 8443, using both a Wratten 15 and a Wratten 32 + 2A filter combination.

Extensive ground photography was obtained to support the aerial photointerpretation phases.

PHOTOINTERPRETATION

Interpretive analyses were made, comparing the project photography with existing USDA scale 1/20,000 pan-minus-blue coverage which had been flown three years earlier in the fall of 1962.

All photography was interpreted at the Itek Data Analysis Center facility in Alexandria, Virginia. Comparative analysis were made using an Itek AM-4 Variable-Width Rear Projection viewer, Zeiss mirror stereoscopes, Union Instrument folding stereoscopes, and related equipment. The film types were evaluated against each other to determine relative image content and ease of interpretation. The ease of detecting and identifying images of archaeological significance at different scales was evaluated by comparing the number of sites detected, and the density of detail which could be identified.

FINDINGS

In the course of our analyses, we found every site which had been found by professional archaeologists on the ground over a fifteen year period. We found a few additional sites which had not been found in field study. One of these was the fortified village shown in Figure 1. In addition, an Indian grave was discovered - the first burial site to be discovered in the area. These findings should not be misinterpreted to mean that photoarchaeology can replace field work; it cannot. The two must go hand-in-hand.

Many of the sites could be located on the 1/20,000 USDA photography, and almost all of them on the 1/10,000 scale pan-minus-blue photography that was obtained for the project. The modified infrared was much less useful than had been expected.

The major advantage found in the use of the color infrared photography was the improvement in interpretation accuracy. Some circular patterns which looked like house pits in the pan-minus-blue photography were found on re-examination to the earth scars which remained following removal of haystacks. Six of these circular patterns are shown in Figure 4. The similarity of these patterns to the dark center pattern of house pits can be seen by comparison with Figure 3.

The principal advantage of the color and color-infrared photography was that it simplified and speeded-up the interpretation.

CONCLUSIONS

Photoarchaeology can be a valuable tool for archaeological reconnaissance. Field exploration which may otherwise take months to conduct can be performed in just a few hours by stereo study of vertical aerial photography; we believe that this is a general conclusion. Regarding the specific types and scales of aerial photography, our conclusions are limited to exploration along the Missouri River. In that area we conclude that pan-minus-blue at 1/10,000 scale is adequate for preliminary reconnaissance, considering time and cost factors, and the convenience of being able to take paper prints and a folding stereoscope into the field. For more detailed reconnaissance, particularily in inaccessible areas which cannot be field checked conveniently, color infrared photography at 1/10,000 scale is preferred.

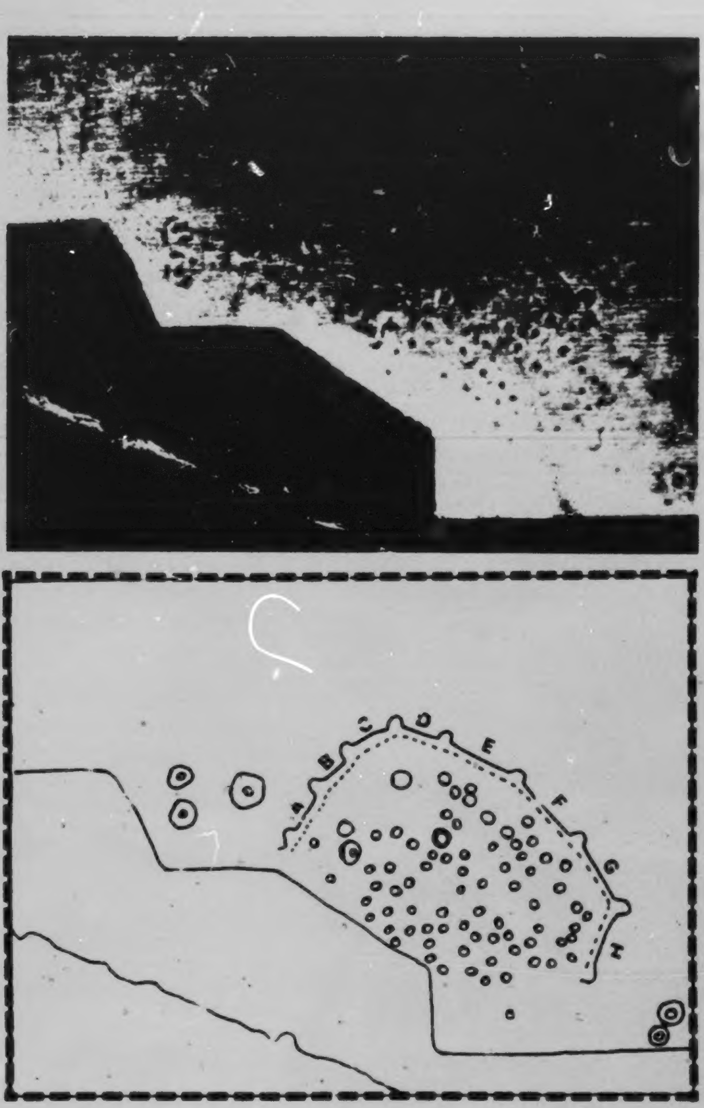


Figure 1. This photo and accompanying sketch map illustrate the present-day appearance of a fortified village site, classified as Pre-Arikara. The solid outer line on the sketch map marks the location of the moat. The dashed inner line marks the location of the palisade. The smaller circles mark the locations of the older houses which were occupied at the time that the moat and palisade were actively defended. The larger double circles mark the locations of more recent Indian earth lodges. Residual traces of these features can be seen in the photo. The distances between the centers of the bastions are:

A - 124 feet   C - 129 feet   E - 209 feet   G - 195 feet
B - 121 feet   D - 135 feet   F - 218 feet   H - 202 feet

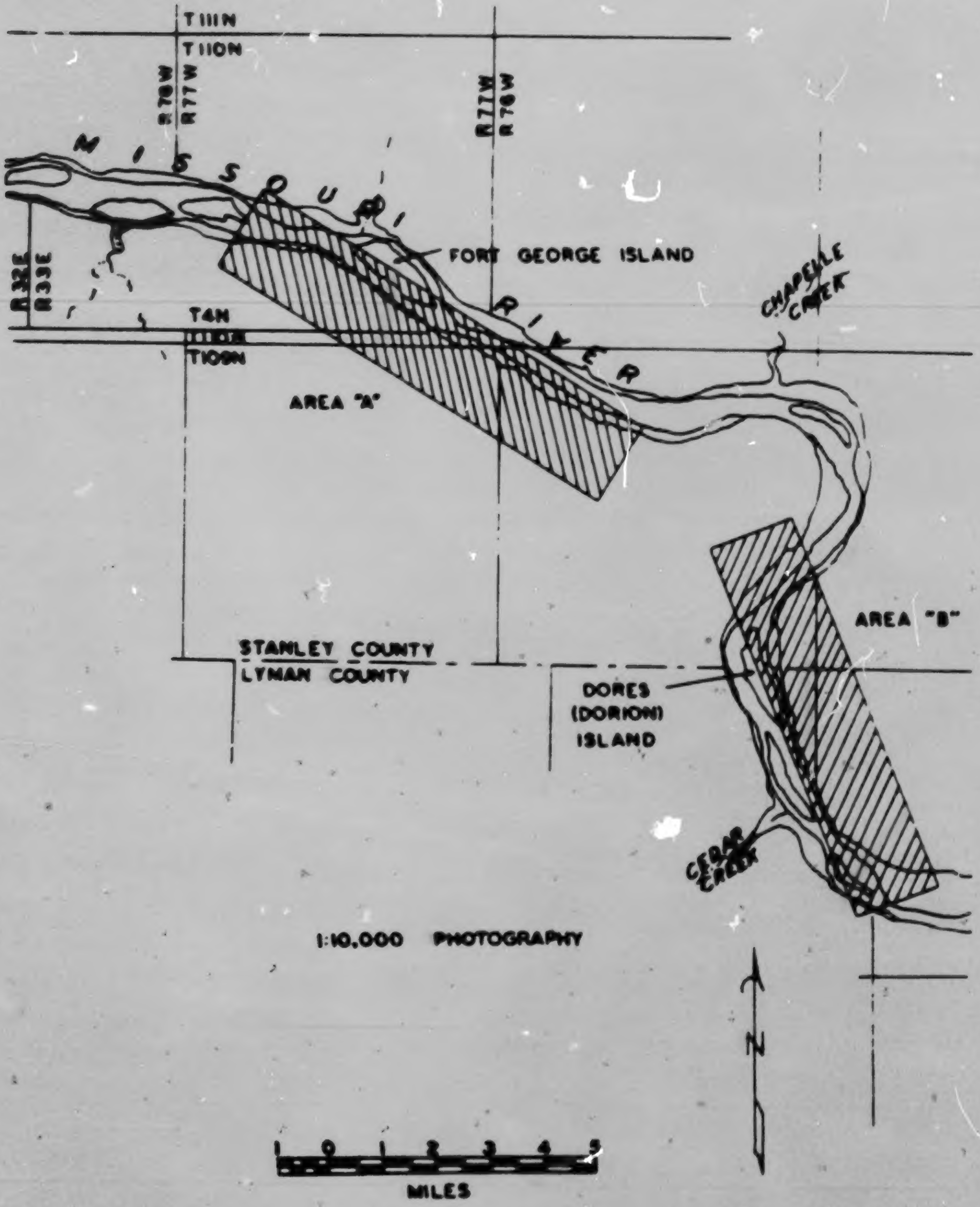

T111N
T110N
R78W
R77W
R77W
R76W
MISSOURI RIVER
FORT GEORGE ISLAND
CHAPELLE CREEK
R32E
R33E
T4N
T109N
AREA "A"
AREA "B"
STANLEY COUNTY
LYMAN COUNTY
DORES (DORION) ISLAND
CEDAR CREEK
1:10,000 PHOTOGRAPHY
N
1 0 1 2 3 4 5
MILES

Figure 2. The test area is located south of Pierre, South Dakota, along the Missouri River as shown in the photo cover diagram.

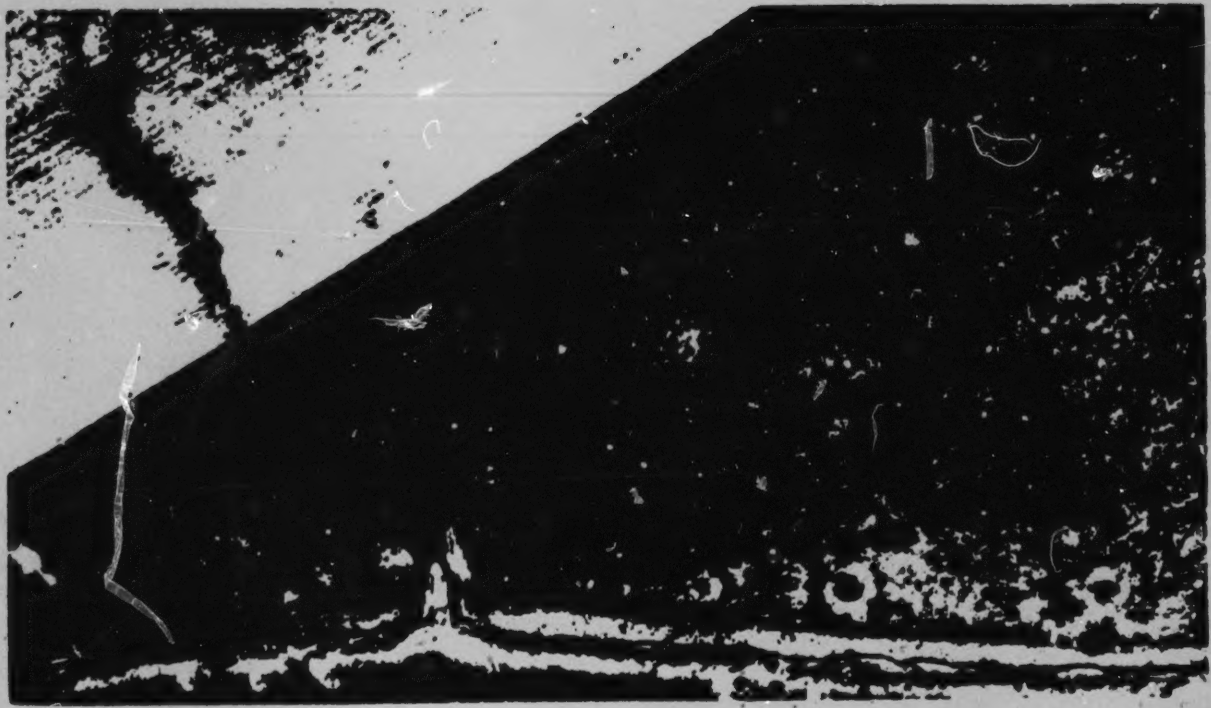


Figure 3. This photo illustrates the appearance of typical earth lodge traces A without cache pits and B with cache pits. The site with cache pits near the center of the photo has been excavated. The small white patches in the field are ant hills. They average about six feet in diameter.

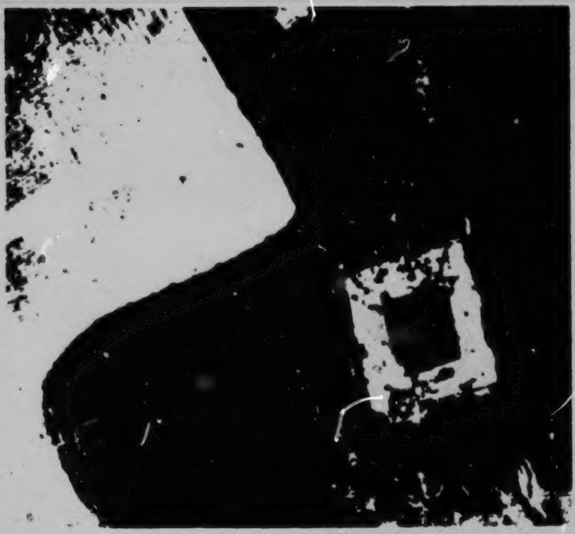


Fig. 4. This photo shows the circular images which mark the former locations of haystacks. These images resemble the dark images which are created by the denser vegetation in the centers of house pits. While they look almost alike in pan-minus-blue photography, they are strikingly different in infrared--particularly color infrared--photography. The rectangular excavation, incidently, marks the remains of Ft. George, a "whiskey trading" fort which was established in 1840.

PHOTOARCHAEOLOGY

Vocabulary - Define the following terms in detail.

Archaeological	Color infrared
1/20,000	
False Color	
Photoarchaeology	
I. R.	

Questions - Answer the following inquiries in detail.

1. What was the purpose of archaeological study along the Missouri River?
2. What was the historical reference in this study?
3. Discuss the experimental procedure and include all controls.
4. What is the mean figure of the distance between the centers of the bastions?
5. Explain the test site.
6. Discuss the test procedure.
7. Why were three altitudes used?
8. Explain photointrepretation.
9. Discuss the principal investigator's findings.
10. What conclusions were drawn and why?

Discussion Topics

1. Discuss the possibility of an archaeological dig of a local Indian mound.
2. In archaeology, why is the old saying "haste makes waste" a valid statement?

APPLICATION OF COMPUTER PROCESSED MULTISPECTRAL DATA TO THE DISCRIMINATION OF LAND COLLAPSE (SINKHOLE) PRONE AREAS IN FLORIDA

Principal Investigators

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R. MARSHALL	University of Michigan
N. S. THOMSON	University of Michigan

Proceedings of the Sixth International Symposium
on
Remote Sensing of Environment
October 1969

ABSTRACT

The U. S. Geological Survey and the Infrared and Optics Laboratory of the University of Michigan jointly collected data near Bartow, Florida, for the purpose of studying land collapse phenomena using remote sensing techniques. Data obtained using the MULTISPECTRAL SCANNER SYSTEM consisted of various combinations of 18 SPECTRAL BANDS ranging from 0.4 - 14.0 MICRONS and several types of photography.

Since areas prone to active sink collapse often are not detectable from apparent surface expression of HYDROLOGY and geology prior to actual collapse, it was necessary to apply indirect methods to the problem of detecting the surface effects caused by water pressure decline in the areas of active sinkhole development. An experiment was conducted to collect and process data for the purpose of testing the hypothesis that areas of active sinks could be detected at the land surface from the integrated effects of water loss at depth on vegetation physiology and terrain temperature.

The MULTISPECTRAL data were processed on the University of Michigan's special-purpose analog computer in order to detect moisture-stressed vegetation and to enhance terrain surface temperatures. The processed results were printed on film to show the patterns of distribution of the proposed HYDROGEOLOGIC indicators. Terrain temperature patterns (obtained from processed 8-14 μm data), when compared with moisture-stressed vegetation patterns (obtained from processed 1-2.6μm data), show distinctive patterns which correlate with areas of known sinkhole activity in the Bartow area. Analyses of National Aeronautics and Space Administration data and field data seem to indicate that the processed data have potential for locating areas of impending land collapse.

INTRODUCTION

The study area which is located at the headwaters of the Alafia and Peace River basins near Bartow, Florida (Figure 1), is underlain by carbonate rock. As during periods of emergence of peninsular Florida in the geologic past, the area is presently undergoing solution by circulating ground water. Much of the past sinkhole formation has been buried beneath as much as 300 feet of interbedded sand, silt, clay and marl. The area is presently emerged and sinkholes are forming.

The quartz sand of PLEISTOCENE age which blankets the surface is underlain by phosphatic clays and sands of the Bone Valley Formation. Locally the Bone Valley Formation unconformably overlies the Hawthorne Formation in which many sinkholes have formed. The sinkholes developed in the Hawthorne Formation are probably the result of solution of the underlying carbonate rocks. Buried sinkholes formed in the top of Hawthorn Formation underlie this area of present day sinkhole occurrence and development (Figure 2, J. B. Cathcart, written communication, 1969).

Ground water in surficial sand percolates through semipermeable confining beds of the Bone Valley and Hawthorn Formations into the underlying carbonate (Floridan) aquifer. Downward movement of this water is concentrated in places where these confining beds are thin, absent, or breached by sand-filled sinkholes.

The larger voids within the Floridan aquifier limestones and relic sinkholes may be filled or partly filled with porous sand so that the overall vertical permeability of the geologic section, from land surface to deep in the Floridan aquifer, is greater than in adjacent areas. Ground water in near surface aquifers should infiltrate into an underlying carbonate aquifer (the Floridan aquifer) more readily at these places of greater permeability.

Water levels in surficial unconfined aquifers in these areas of greater vertical permeability should decline more than in surrounding areas and a cone of depression, somewhat similar to that formed in the vicinity of a discharging well, should form. Because of continued drainage, the water content of the soils overlying these areas of greater vertical permeability is reduced considerably more than in the soils of surrounding and less well-drained areas.

During seasons of heavy rainfall, the percolation of somewhat acid water into the Floridan aquifer through these zones of greater vertic permeability should allow progressive carbonate solution of the Floridan aquifer. Such chemical solution can enlarge the underground conduits and weaken the roof that supports the overlying material. However, during rainy seasons when the recharge exceeds discharge, HYDROSTATIC pressure within the aquifer will be increased. This increased pressure helps support the weakened roof and prevents collapse by reducing stress on the rocks.

During dry seasons as the water levels decline, hydrostatic pressure partially supporting cavern and conduit roofs may decline enough so that the load stress caused by the overlying material exceeds mechanical strength of the cavern roofs and collapse occurs (Figure 3). In the test area, industrial and agricultural expansion has led to a marked increase in the use of water from the Floridan aquifer. This continuing increase in use of water coupled with a six year drought has caused a progressive decline of hydrostatic pressure which has probably accelerated the natural process of sinkhole formation.

A greater probability for the formation of sinkholes is hypothesized to occur during and shortly after times of greatest hydrostatic pressure or water level decline, and in areas underlain by buried relic sinkholes. The objective of this study was to determine the capability of MULTISPECTRAL REMOTE SENSING techniques to locate areas of impending land collapse.

Multispectral data were acquired by the University of Michigan's airborne 18-channel optical-mechanical SCANNER over a test area near Bartow, Florida on 6 September 1967 at 0647 hours, and 5 September 1967 at 1224 hours. Each flight was made at an altitude of 2000 feet above terrain (Figure 1). These data have been processed using multispectral techniques in order to detect moisture stressed vegetation and to enhance surface thermal effects. The processed results have been correlated with hydrogeologic field data to determine the capability of using the processing techniques to detect and map areas of impending collapse. This paper will be devoted to an interpretation of the processed images obtained by the automatic computer processing techniques at the Infrared and Optics Laboratory of the University of Michigan. Detailed descriptions of the 4 methods of collection and processing of the data are published in papers by Holter and Polcyn (1965), Holter and Wolfe (1960), Lowe and Braithwaite (1966), Malila (1968), and Marshall (1969).

THREE-CHANNEL REFLECTIVE INFRARED PROCESSING

Three-channel reflective infrared data (0.1 - 1.4 μm, 1.5 - 1.8 μm, 2.0 - 2.6 μm) collected on 5 September 1967 at 1224 hours were selected for processing on the University of Michigan's Spectral Analyzer and Recognition Computer for the detection of moisture-stressed vegetation. Four training-set areas were selected which apparently represented four different vegetation moisture-stress conditions thought to have been induced by sinkhole formation (Figure 4).

The training-set areas chosen were:

1. Dry herbaceous marsh vegetation
2. Dry grass vegetation located along the west edge of a relic sinkhole
3. Dry grass vegetation located along the west edge of the relic sinkhole but nearer the center
4. Dry grass vegetation located near the east edge of the relic sinkhole

The signatures obtained for each training-set consisted of the radiance mean and standard deviation values in each spectral band (covariances were not included). The computer was programed to compute the sum of the squares of the deviations about the mean for each point and to accept or reject the point on the basis of the magnitude of the sum. The decision level was arbitrarily set to yield a satisfactory ratio of target detection and background rejection. (Editor's Note: These statistical techniques were used to produce a more accurate signature. The student need only understand their purpose at this time.)

Each SIGNATURE was employed one at a time, to make strip maps. Color-coded ozalid prints representative of each of the four recognition signatures were made from these maps and overlaid to form a composite recognition map of apparent moisture-stressed vegetation (Figure 5a, Table 1a).

TEMPERATURE SLICING PROCESSING

Using Michigan's processor, twelve separate filmstrip maps were produced from 8-14 μm data with each separate filmstrip representing increments of apparent surface temperature between 77°F and 98.5°F. Although the actual ground temperatures represented in the data are not known, relative temperature information can be inferred. Each filmstrip was assigned a different color and copied on a colored ozalid foil (Table 1b). These color foils were overlaid and displayed against an 8-14 μm black and white video background to form a twelve-color composite thermal map (Figure 5b).

ANALYSIS

The scanner data were collected during a drought when the shallow water table had declined markedly. Soil composition and drainage properties in the vicinity of the large relic sinkhole were determined by test drillings. The soils are mixtures of silty

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organic matter and fine-to medium-grained sands having similar drainage properties. Measurements of water levels in wells in the same vicinity revealed that the water table slopes downward toward the areas of recent sinkhole collapse within the large relic sinkhole. Excluding minor irregularities caused by puddling and topographic ANOMALIES, surface temperature conditions could be expected to reflect the general water table configuration. Moisture-stressed vegetation was considered a secondary surface indicator of excessively drained soils.

The thermal scanner data were collected on 6 September 1967 at 0657 hours. At this time, one would expect the dry excessively drained soil surrounding sinkholes to be cooler than the soils which were not excessively drained by sinkhole formation. The thermal contour map shows four different temperature intervals (80.5°F, 82.0°F, 83.5°F, and 85.0°F) within the large relic sinkhole on the western side of US 98 (Figures 5b and 6). Within the relic sinkhole feature, the cooler temperature contours (80.5°F, orange; and 82.0°F, black) delineate areas of active subsidence. The warmest temperature interval within the relic sinkhole (85.0°F, red) occurs near the center of one of the collapse holes and at the outermost margin of the relic sinkhole feature. The area near the center of the large collapse hole had formed a hardpan layer and therefore was more moist than the adjacent soils. The patterns of detection of moisture-stressed vegetation obtained from the processed reflective IR data (Figure 5a) correspond well in shape and location to the distribution of the cooler temperature contours (Figure 5b). For example, the pattern of detections of moisture-stressed vegetation within the relic sinkhole obtained from processing with training set 3 (Table 1a, Figures 4, 5a) lie almost entirely within the coolest temperature zones of the sinkhole (80.5°F, orange; and 82.0°F, black). Field observations revealed that the relic sinkhole is underlain by a mantle of sand and a lime-sink (Figure 2).

Other oval patterns observed in the reflective and thermal IR processed data (September 1967) delineated several other known sinkhole areas, as well as an area where subsidence did not begin until the late summer of 1968 (Figures 5a, 5b, and 6). This area of most recent subsidence is located about 3000 feet north of the active sinkhole area discussed above.

CONCLUSIONS

Multispectral scanning and processing should prove to be useful tools for conducting HYDROGEOLOGIC surveys of karst areas. From this study, it is concluded that locating areas of future land subsidence by multispectral remote-sensing techniques is feasible. It is particularly significant that these techniques appear to have potential for locating hydrogeological phenomena occurring as much as 100 feet below the surface of the earth.

These applications have involved intensive collaboration of personnel engaged in remote-sensing techniques at the Infrared and Optics Laboratory, University of Michigan, and those Geological Survey hydrologists familar with the hydrogeology of the Bartow area near Tampa, Florida. It has proven true that very close cooperation across the disciplines involved in such research is extremely important for significant progress, and such cooperation has taken place in this work.

ACKNOWLEDGEMENTS

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TABLE 1a

COLOR KEY FOR SINK AREA VEGETATION

Training-Set Number	Color	Feature
1	Blue	Dry herbaceous marsh vegetation
2	Green	Dry grass vegetation located along the west edge of a relic sinkhole
3	Red	Dry grass vegetation located along the west edge of the relic sinkhole but nearer the center
4	Brown	Dry grass vegetation located near the east edge of the relic sinkhole

TABLE 1b

COLOR KEY FOR FALSE COLOR THERMAL CONTOURING IN SINK AREA

Color	Average Apparent Surface Temperature (°F)
Cyan	77.0
Violet	79.0
Orange	80.5
Black	82.0
Yellow	83.5
Red	85.0
Blue Green	86.5
Dark brown	88.0
Yellow green	90.0
Magenta	93.0
Olive	96.0
Dark blue	98.5

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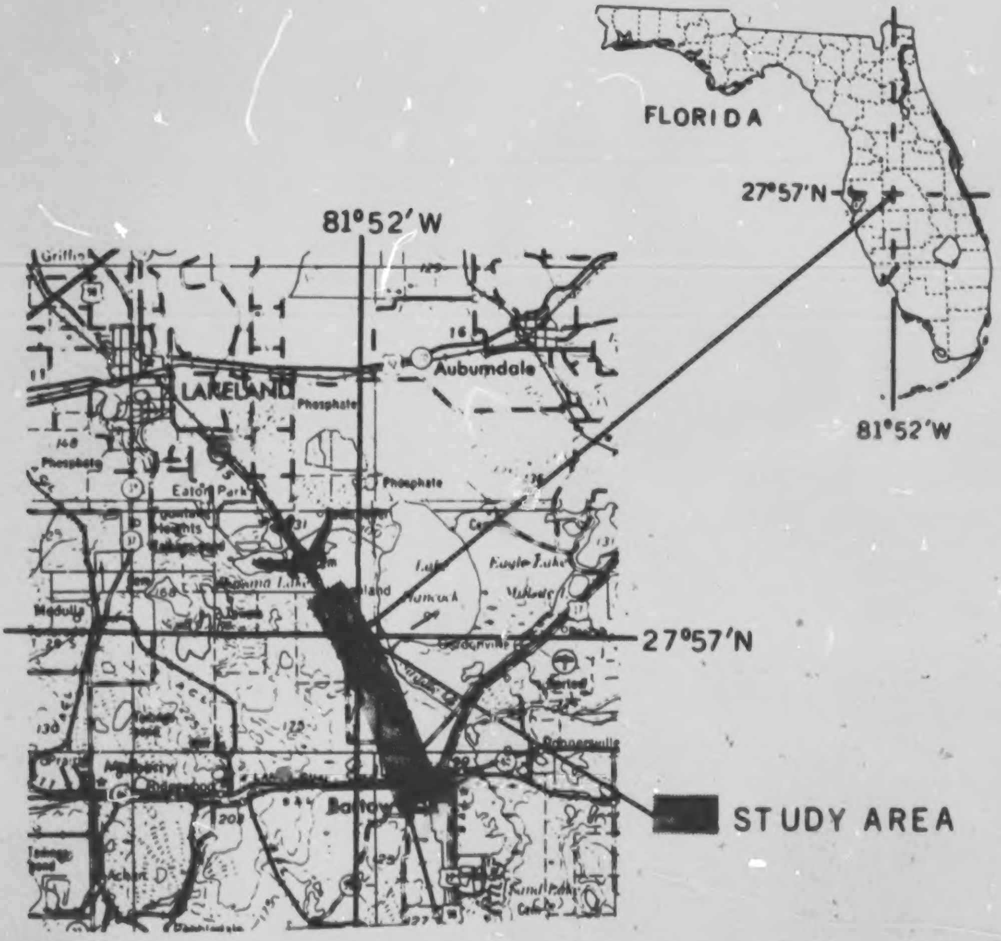
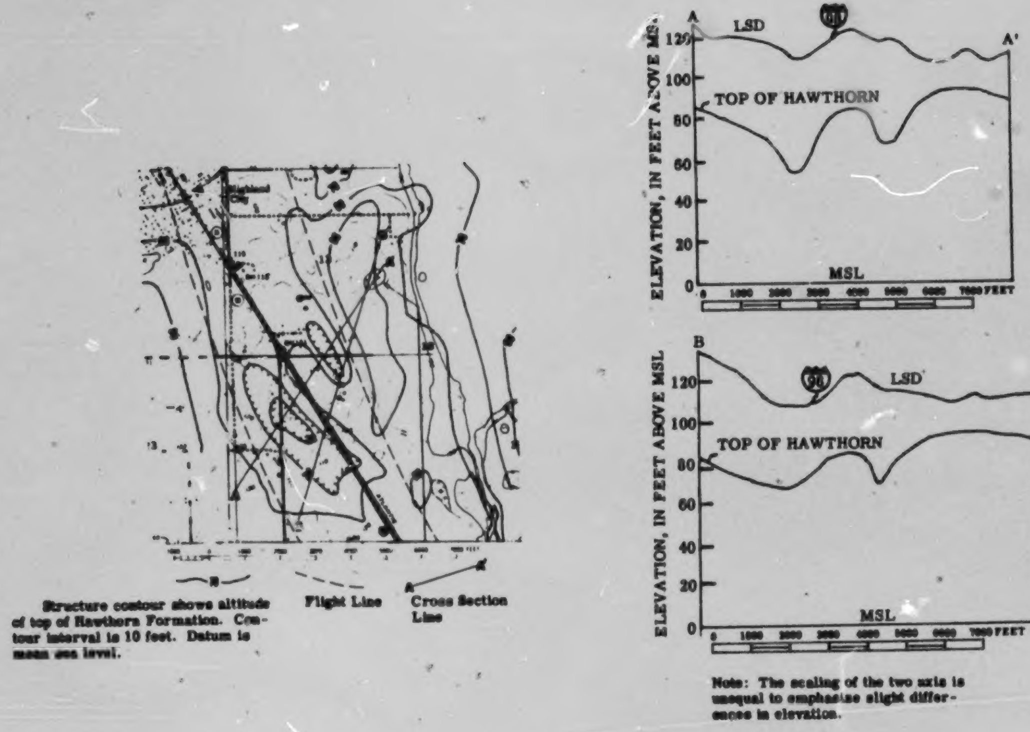

FLORIDA
27°57′N
81°52′W
81°52′W
27°57′N
LAKELAND
Aubumdale
Phosphate
Eaton Park
Eagle Lake
STUDY AREA

Figure 1. INDEX MAP OF STUDY AREA. The shaded area outlines the approximate area covered by Michigan's airborne multispectral scanner on September 5th and 6th, 1967.


Flight Line
Cross Section Line
A
LSD
A'
ELEVATION, IN FEET ABOVE MSL
120
100
80
60
40
20
0
TOP OF HAWTHORN
MSL
0
1000
2000
3000
4000
5000
6000
7000 FEET
B
LSD
B'
TOP OF HAWTHORN
95

Structure contour shows altitude of top of Hawthorn Formation. Contour interval is 10 feet. Datum is mean sea level.

Note: The scaling of the two axis is unequal to emphasize slight differences in elevation.

Figure 2. MAP AND CROSS SECTION OF RELIC KARST TOPOGRAPHY. Sand-filled sinkholes formed in limestones of the Hawthorn Formation underlie the study area at depths as much as 50 feet beneath the land surface. Land collapse is hypothesized to occur more frequently in areas underlain by buried relic sinkholes as indicated by the configuration of the top of the Hawthorn Formation (from unpublished map by Cathcart).

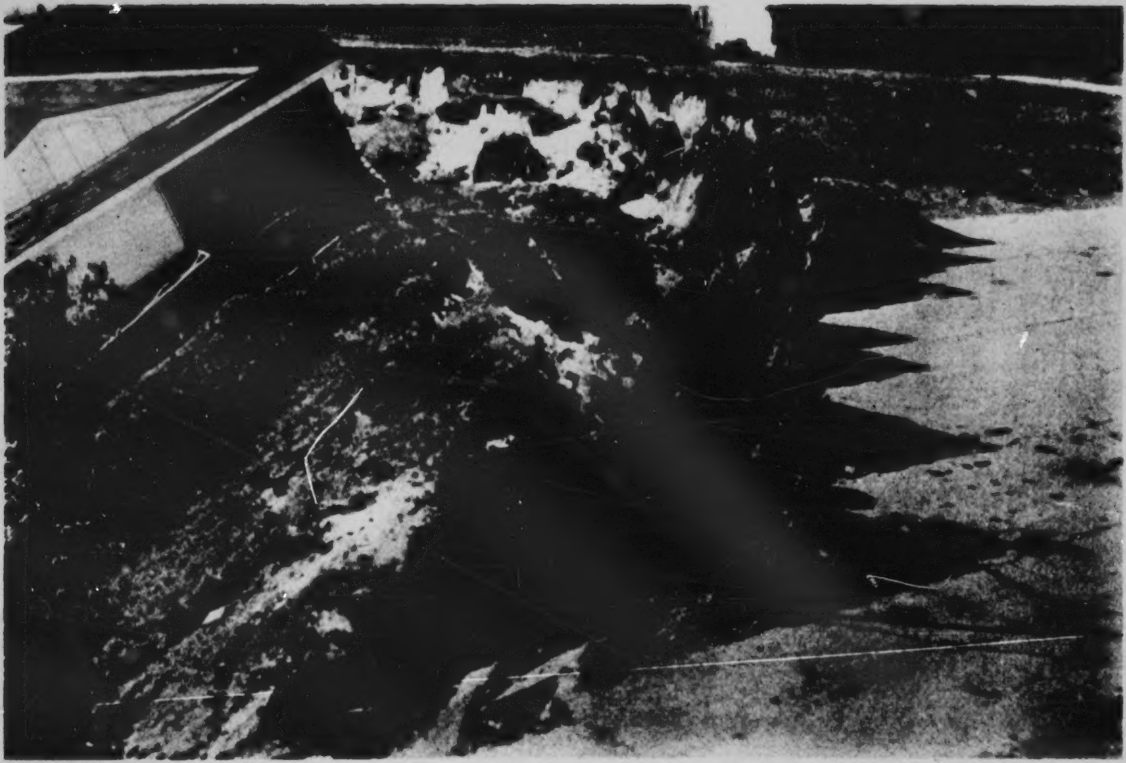


Figure 3. ONE OF TWO HOMES LOST IN LAND COLLAPSE IN BARTOW, FLORIDA, May 22, 1967. Sinkhole that formed was 520 feet by 125 feet and 60 feet deep.

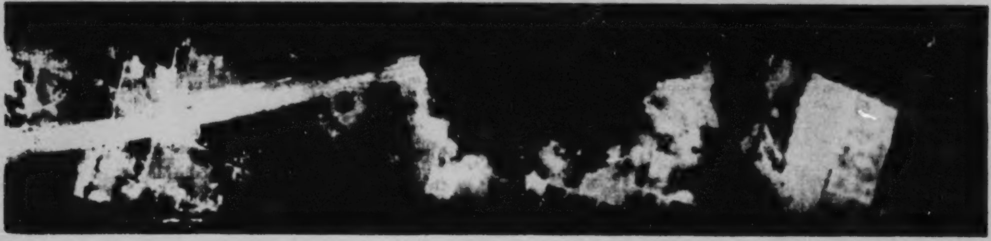


Figure 4. MAP SHOWING LOCATIONS OF TRAINING SETS USED FOR PROCESSING 3-ELEMENT IR SCANNER DATA. The training sets are displayed against a 1.0-1.4 μm video background.

TS 1	Dry marsh vegetation
TS 2	Dry grass along western edge of active sinkhole
TS 3	Dry grass near center of active sinkhole
TS 4	Dry grass near eastern edge of active sinkhole

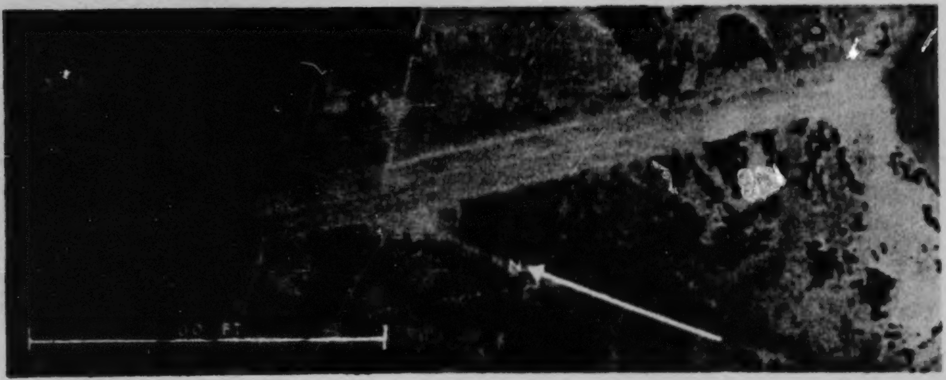


Figure 5a. COLOR CODED RECOGNITION MAP OF MOISTURE-STRESSED VEGETATION IN KARST AREA. The composite recognition map is displayed against a 1.0-1.4 μm video background. Each recognition map is coded in a different color (see Table 1a). The circular patterns along US Highway 98 to the left of the center part of the photograph show the area of active subsidence. Less obvious patterns, about 3000 ft. north of the active sinkhole test site are suggestive of sinkhole formation. The recognition maps are processed using data acquired by The University of Michigan's airborne multispectral scanner system, near Bartow, Florida, 5 September 1967 at 1224 hrs., altitude 2000 ft. above terrain.

Figure 5b. COLOR CODED THERMAL MAP OF KARST AREA. The composite thermal contour map depicts twelve different temperature contours between 77 deg. F. and 98.5 deg. F (See Table 1b). The relatively cooler surface temerature zones which form concentric patterns along the west side of Highway 98 to the left of the center part of the photograph show the area of active subsidence. Other patterns suggestive of sinkhole formation occur about 3000 feet north of the active sinkhole.

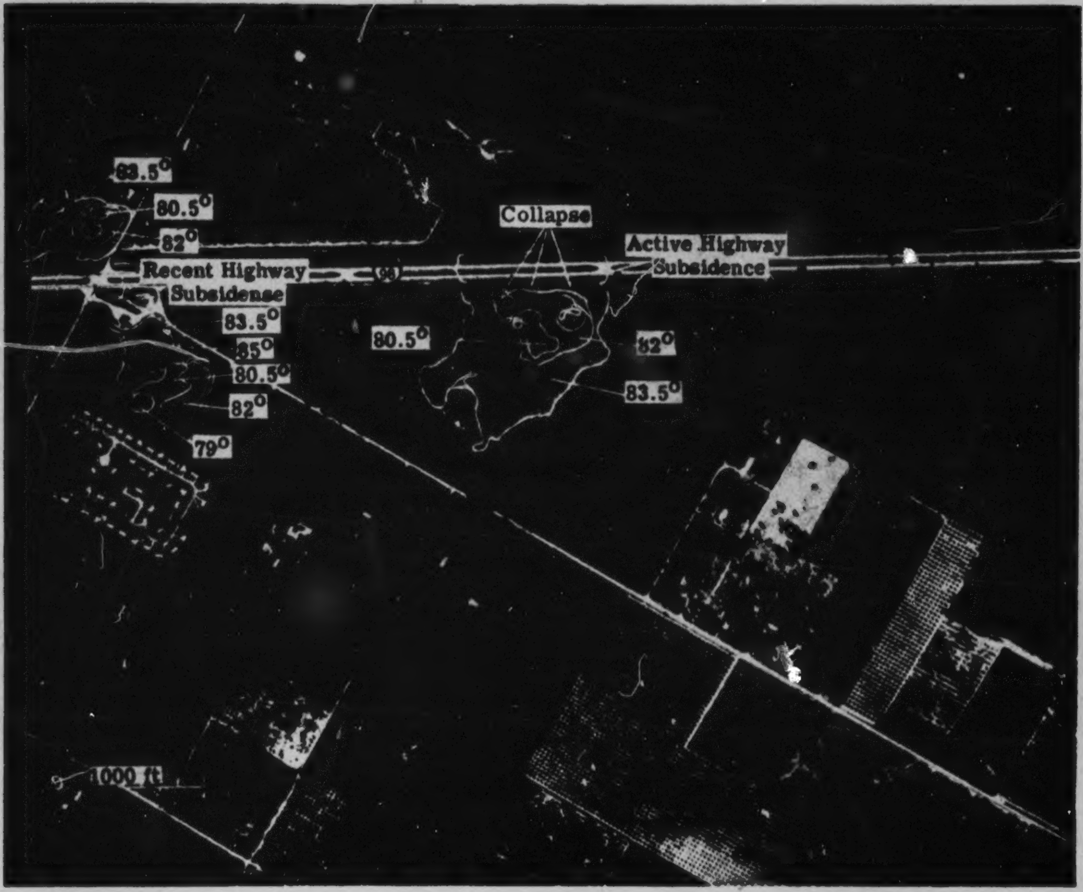

83.5°
80.5°
82°
Recent Highway Subsidense
98
83.5°
85°
80.5°
82°
79°
80.5°
Collapse
Active Highway Subsidence
82°
83.5°
1000 ft

Figure 6. PHOTOGRAPH OF STUDY AREA SHOWING THERMAL ZONES AND AREAS OF SUBSIDENCE NEAR BARTOW, FLORIDA. Surface temperatures were derived from data acquired by The University of Michigan's airborne multispectral scanner system. Photograph was taken by NASA for mission 85, site 146, 14 January 1969 at 1920 hrs. altitude 4500 ft. above msl. Cooler surface temperature zones delineate the dry areas of deeper water levels and subsidence.

SINKHOLES

Vocabulary - Define the following terms in detail.

- Multispectral scanner system
- Micron bands
- Hydrogeologic
- Gaussian
- Terrain
- Sinkhole
- Pleistocene
- Aquifer
- Carbonate aquifer
- Hydrostatic pressure
- Anomalies
- Headwaters
- Karst

Questions - Answer the following inquiries in detail.

1. Why does the author compare terrain temperature with moisture stressed vegetation patterns?
2. What is ground water percolation?
3. Why is acid water percolation greater after/during heavy rainfall?
4. When hydrostatic pressure drops in the dry season, what is the stress factor?
5. What four areas were selected as related to vegetation moisture stress?
6. What is temperature slicing?
7. Why do moist soils have greater conductivity than dry soils?
8. How is multispectral scanning used in hydrogeologic surveys of karst terrain?

Discussion Topics

1. Explain the geological phenomenon surrounding sinkholes.
2. What is the difference between sinkholes and quicksand?

LANDSAT DATA: A NEW PERSPECTIVE FOR GEOLOGY

A review of the utilization of LANDSAT imagery for geological interpretation.

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Photogrammetric Engineering and Remote Sensing,
October 1975, Vol. 41, No. 10

ABSTRACT

The LANDSAT (formerly ERTS) program, while conceived and implemented as a research and development project, has been used as an operational ORBITAL remote sensing system providing data of considerable value to various branches of geology. Areas in which the satellite imagery has been found most useful include regional interpretations of geological structure, updating and verifying of geologic maps, mineral and petroleum exploration, and the monitoring of natural hazards such as large-scale erosion and SEISMICITY. Investigations in these areas of application demonstrate the wide variety of uses presently undertaken or envisioned for the future. Many benefits have already been felt; others will be seen in the near future where the promise of mineral or petroleum concentration will be realized through conventional ground based and satellite exploration techniques. LANDSAT will aid considerably in pinpointing the likely site; "hands on" geology will do the rest.

INTRODUCTION

The LANDSAT (formerly ERTS) satellite program has been in existence for just over two years, and in this brief time has added a whole new dimension to the study of our Earth. Scientists from all over the world have used data measured by LANDSAT's SENSORS (telemetered down from a 580-mile-high vantage point in space) to monitor pollution and crop growth, explore for minerals and petroleum, and conduct a host of other investigations ranging from animal migration patterns to iceberg monitoring. The mission, originally designed for research and development, has for all practical purposes been considered "operational" from the user's point of view.

To geologists, the regional overview and repetitive coverage of LANDSAT data has been particularly useful, enabling them to take advantage of vegetation and sun angle changes in their attempts to unravel the physical history and setting of the Earth. Successful LANDSAT investigations in geology can be grouped for convenience into four general categories: regional structural studies, geologic mapping, mineral and petroleum exploration, and natural hazards surveys. The categories are arbitrary, and results of investigations might fit equally well into more than one of these.

REGIONAL STRUCTURAL STUDIES

Several investigators studied regional structures and their relationships in LANDSAT imagery, availing themselves of a perspective previously impossible to achieve. Y. Isachsen of New York State's Geological Survey used the 100-by-100 mile images to construct a mosaic of the State and neighboring regions. This mosaic shows, at a glance, geologic relationships of New York State's diverse terrain, major rock units, glacial features, large scale lineaments, and circular structrues (Figure 1). Isachsen went into the field to verify the existence of many of these features discovered in the LANDSAT mosaic, and demonstrated how one could use satellite imagery to discern features unsuspected at a larger scale.

Houston and Marrs, LANDSAT investigators from the University of Wyoming, studied geologic structures in Wyoming by using a LANDSAT mosaic, and reported that their interpretations compared favorably with known ground truth of the region. While this region had been reasonably well mapped by conventional field surveys, the Houston-Marrs study points out the possibility of interpreting poorly mapped regions with a minimum of GROUND TRUTH, time, and cost with some measure of confidence.

In the East where climate is generally less arid than in some Western States, LANDSAT investigators have still been able to collect valuable geologic information despite the heavier vegetation cover. For example, regional linaments were discovered and mapped by Gold and co-investigators at Penn State, using LANDSAT imagery of the thickly forested Pennsylvania Appalachians. A private consulting firm has applied computer-aided ENHANCEMENT TECHNIQUES (in this case General Electric Company's IMAGE 100 multispectral image processing and display system) to imagery of other areas in eastern Pennsylvania, with success in distinguishing rock outcrops of limited areal extent. Thus, while imagery of arid regions has the obvious advantage of little interference between surface and SENSOR, investigators have shown that much geological information can be derived from imagery where the ground is obscured by vegetation.

GEOLOGIC MAPPING

The LANDSAT overview and coverage cycle makes map correction and verification a natural application to geology. Investigators H. Blodget and A. Anderson of NASA's Goddard Space Flight Center constructed a three-image mosaic of southern Morocco from which they were able to verify and modify previously mapped LITHOLOGIC boundaries, and investigate relationships between structural character and mineral emplacement from a regional perspective. A common procedure among LANDSAT investigators has been to use the imagery as base maps upon which geologic interpretations of structure, LITHOLOGY, and LINEAMENT patterns are superimposed. Another team of investigators, M. Abdel-Gawad and J. Silverstein of Rockwell International, discovered that LANDSAT images of Baja and the Gulf of California showed several small islands to have been misplaced on conventional maps, both in geographic location and in topographic detail.

M. Viljoen of South Africa used LANDSAT imagery to unravel the geologic relationships of the South African shield. This investigator was able to distinguish between the granite-gneiss craton, adjacent METOMORPHIC mobile belts, and major "greenstone" intrusions. The nature of these intrusions and their characteristic relationship to the overall geologic setting was recognized by Viljoen to be similar to that found in metallic mineral mining districts in Canada (e.g., Sudbury, Ontario) and Western Australia, and suggests that the South African regions might contain useful concentrations of minerals as well. In this example, the roughly 34,000-square kilometer region surveyed in a single LANDSAT frame could be broken down into mineralization potential maps with considerable savings in time and cost of mineral exploration interests. On a larger scale, perhaps the most impressive display of LANDSAT's map-making capability can be seen in the mosaic of the 48 counterminous United States, produced by the Soil Conservation Service of the U.S. Department of Agriculture, and available to the public (Figure 2).

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MINERAL AND PETROLEUM EXPLORATION

The majority of LANDSAT geology investigations fall into this category primarily because of the direct impact on current and projected national needs. Mineral exploration from LANDSAT has been accomplished using the following well-known geologic principles:

- Mineralizing fluids from within the Earth may follow the paths of least resistance to the surface; these paths are zones of weakness through the Earth's crust and occur where the solid rock has been fractured and faulted. Thus, a concentration of "LINEAMENTS", many of which can be discerned in LANDSAT imagery, may well indicate where the crust is weakest and, therefore, most likely to be mineralized.
- Some rock types discernible from orbital altitudes are characteristically associated with certain types of minerals because they indicate similar formative conditions or alteration through time.
- Mineralization may alter surface tones by SECONDARY ENRICHMENT, vegetation stress and/or chemical changes in the vicinity of the ore body, all of which can indicate that significant mineral concentration has taken place.

Using these and other, more subtle clues, geologists using LANDSAT imagery have reported varying degrees of success in mineral and petroleum exploration studies. Some of these investigators have related LANDSAT-discovered lineaments to known mineral concentrations; many of these studies have been undertaken in the arid regions of Western North America. E. Lathram and other geologists of the U.S. Geological Survey discovered a series of intersecting regional lineaments in a rare cloud-free NIMBUS image of Alaska. These lineaments were verified in LANDSAT imagery and enabled the investigators to propose a radically different picture of mineral emplacement in Alaska. Earlier speculation suggested that mineral deposits in Alaska were related to fold belts of the Canadian Cordillera. Based on the occurrence of the newly discovered regional fractures, Lathram and his co-workers suggested that mineral emplacement might also have occurred at their intersections. The result is an alternate hypothesis for mineral emplacement in Alaska, certain to stimulate interest in renewed exploration efforts in areas formerly dismissed as non-productive (Figure 3).

Further to the south, California investigators E. Rich (1973), Abdel-Gawad, and Silverstein (1973) correlated mining localities with lineaments observed in LANDSAT imagery. Abdel-Gawad and Silverstein, in particular, correlated mercury mining localities with a newly discovered set of transverse faults in the Coast Ranges. The altered serpentine host rock and geologic setting of the mercury ore were non-definitive and of little value as ore guides. With the relationship demonstrated by these investigators, future exploration efforts should be simplified markedly (Figure 4). Another Californian, I. Bechtold, demonstrated a similar correlation between TENSIONAL FISSURES in the Lake Mead area (resulting from east-west crustal extension) and concentrations of gold, silver and other metallic ore deposits.

An interesting multilevel GEOCHEMICAL exploration approach was reported by M. Jensen, of the University of Utah, who correlated LANDSAT lineaments with positive AEROMAGNETIC ANOMALIES, and field-checked areas where they coincided. Soil samples were analyzed for mercury vapor and those areas of highest mercury vapor concentration identified for intensive exploration.

Other investigators have attempted to correlate mineral deposits with characteristic surface tones extracted from LANDSAT imagery visually or by computer enhancement techniques. R. Vincent identified highly oxidized terrain overlying iron ore deposits in the Atlantic City mining district of Wyoming by computer ratioing REFLECTANCE VALUES of selected pairs of ERTS bands. The results were ANALOG ratio images, corrected for geometric and atmospheric effects, which showed the oxidation "halos" over the iron ore deposits. A. Goetz and others at JPL developed computer techniques for rock identification and structural analysis in the Colorado Plateau, eventually resulting in the discovery of perched aquifers, ground water sources badly needed by ranchers on the Coconino Plateau of southern Arizona.

LANDSAT data have found application in petroleum exploration as well. Two investigations have met with initial success in this area. E. Lathram in another phase of the study mentioned earlier discovered an unusual regional orientation in a series of lakes on the Alaskan Arctic Coastal Plain. The lakes, generally oval in outline, paralleled regional lineations and deviations in the local gravity and magnetic fields. Supporting ground truth coupled with LANDSAT data led the investigators to postulate the existence of "dip" reversals and regional arching; factors which might indicate potential petroleum accumulation (Figure 5). Similar geologic trends continue to the northeast, and have aroused the interest of the petroleum industry.

Another investigation, headed by R. Collins of Eason Oil Company (Oklahoma City), correlated "hazy" surface tones discovered in LANDSAT imagery of the Anadarko Basin (NE Texas and SW Oklahoma) with known producing oil fields. Correlation exceeded 85 per cent, and led the investigators to hypothesize that these surface anomalies were the result of volatile components of the petroleum reservoirs migrating to the surface. Whether this phonomenon is a consequence of well drilling or is a natural occurrence remains to be proven.

EARTH HAZARDS: MONITORING AND SURVEYS

Geologic hazards present a direct threat to society in several familiar ways. The catastrophic result of earthquakes and volcanic eruptions, and the less spectacular but equally devastating effects of erosion and flooding can be monitored and better understood through the synoptic and repetitive overview provided by LANDSAT 1 and 2.

LANDSAT investigators have successfully used orbital imagery to inventory, monitor, and even forewarn of potential geologic catastrophes. Among these are USGS geologists Eaton and Ward, who used LANDSAT to relay information from a series of DATA COLLECTION PLATFORMS emplaced on active, potentially eruptive volcanoes in Alaska and Central America. DCP instrumentation consisted of seismic event counters and bore hole tiltmeters, both designed to relay data characteristics of the pre-eruptive phase of the volcano. The investigation proved successful when the volcano Fuego, in Guatemala, erupted with devastating force shortly after information relayed from the DCP indicated it would.

Other Earth hazards include the potential of earthquakes in many parts of the world. LANDSAT facilities for locating regional lineaments have been used by investigators dealing with these hazards. M. Abdel-Gawad discovered evidence of recent movement along faults in southern California long considered to be inactive. SEISMIC hazards maps can be modified by inputs of this type provided by LANDSAT sensors.

L. Gedney of the University of Alaska's Geophysical Institute constructed a mosaic of central Alaska using six LANDSAT images, clearly revealing the presence of sets of "lineaments" (faults and fractures) which correlated well with the distribution of shallow focus earthquake EPICENTERS in the region. Through these studies, an active leg of the Denali fault was found to lie close to a bridge site over the Yukon River, and the proposed route of the Alaskan oil pipeline. Updated seismic data coupled with LANDSAT imagery will enable planners to modify their route selections as necessary.

Perhaps less catastrophic but equally devastating in the long term is the problem of soil erosion. Morrison of the U.S. Geological Survey dealt with regions of accelerated erosion in southern Arizona. Present erosion damage was monitored by LANDSAT, flooding and floodwater recession observed, and an erosion-susceptibility map constructed as an aid to future development.

LANDSAT programs have made significant contributions to many subspecialities within geology. Some of these contributions have already been felt in terms of corrected maps and a more accurate awareness of prevailing seismic hazards.

Some will be felt in the future, where the promise of undiscovered mineral and petroleum deposits can be fulfilled through COMPUTER ENHANCEMENT of LANDSAT data combined with visual interpretation and supporting ground truth.

Data collected by LANDSAT's sensors can provide a wealth of information useful for solving the problems facing man as he tries to live in harmony with his environment. Only thoughtful interpretation of the data, supplemented by the technology of modern computers, will enable him to maximize the benefits "for all mankind".

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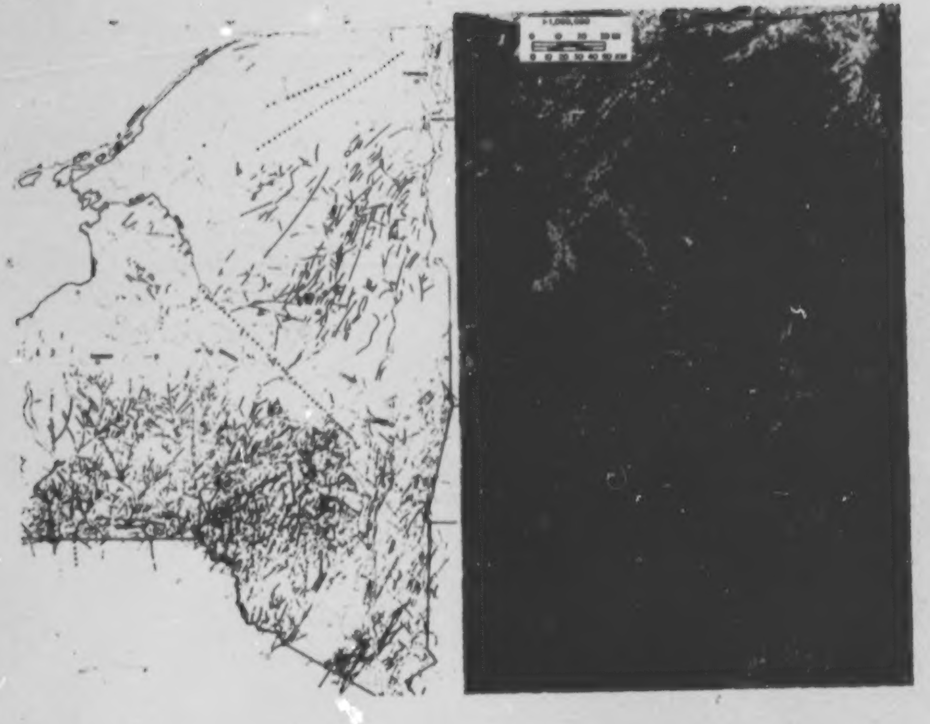

Fig. 1. LANDSAT mosaic and lineament map of eastern New York State (after Isachsen, 1973).

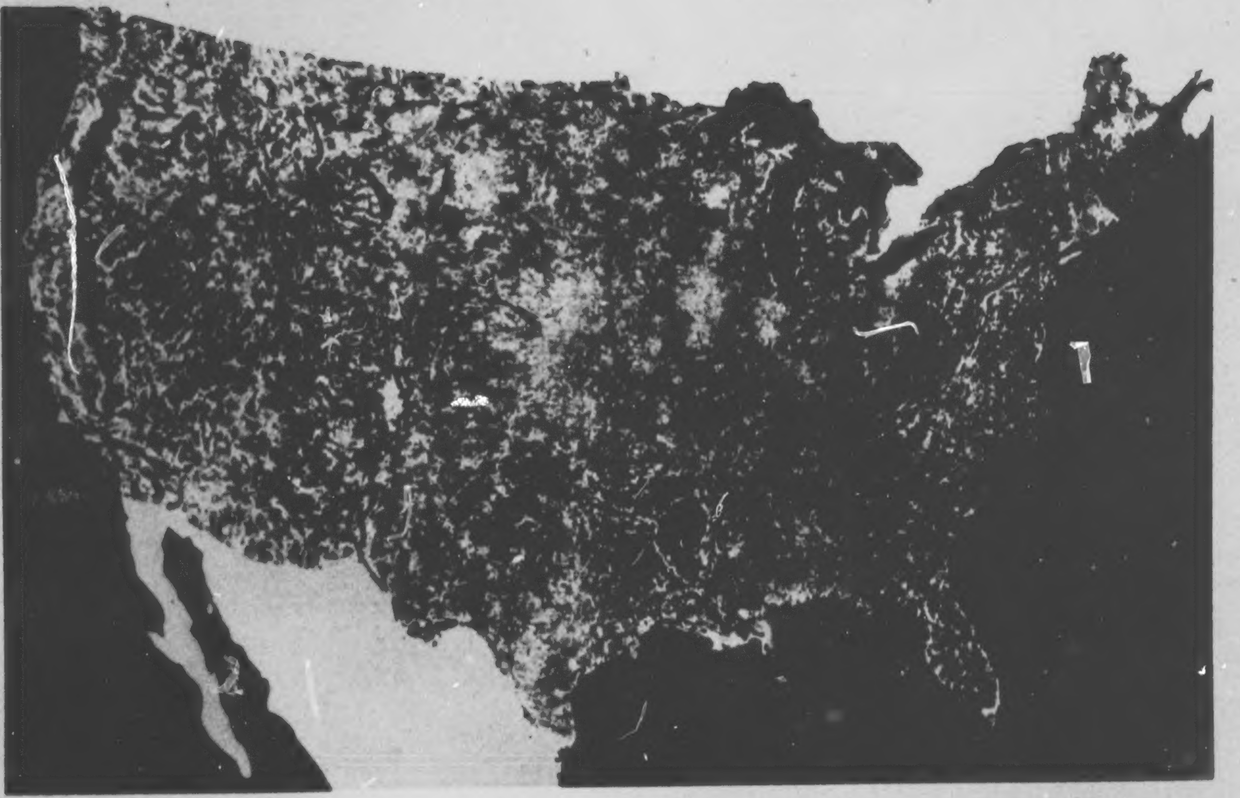

Fig. 2. Mosaic of continental United States compiled from LANDSAT imagery by USDA.

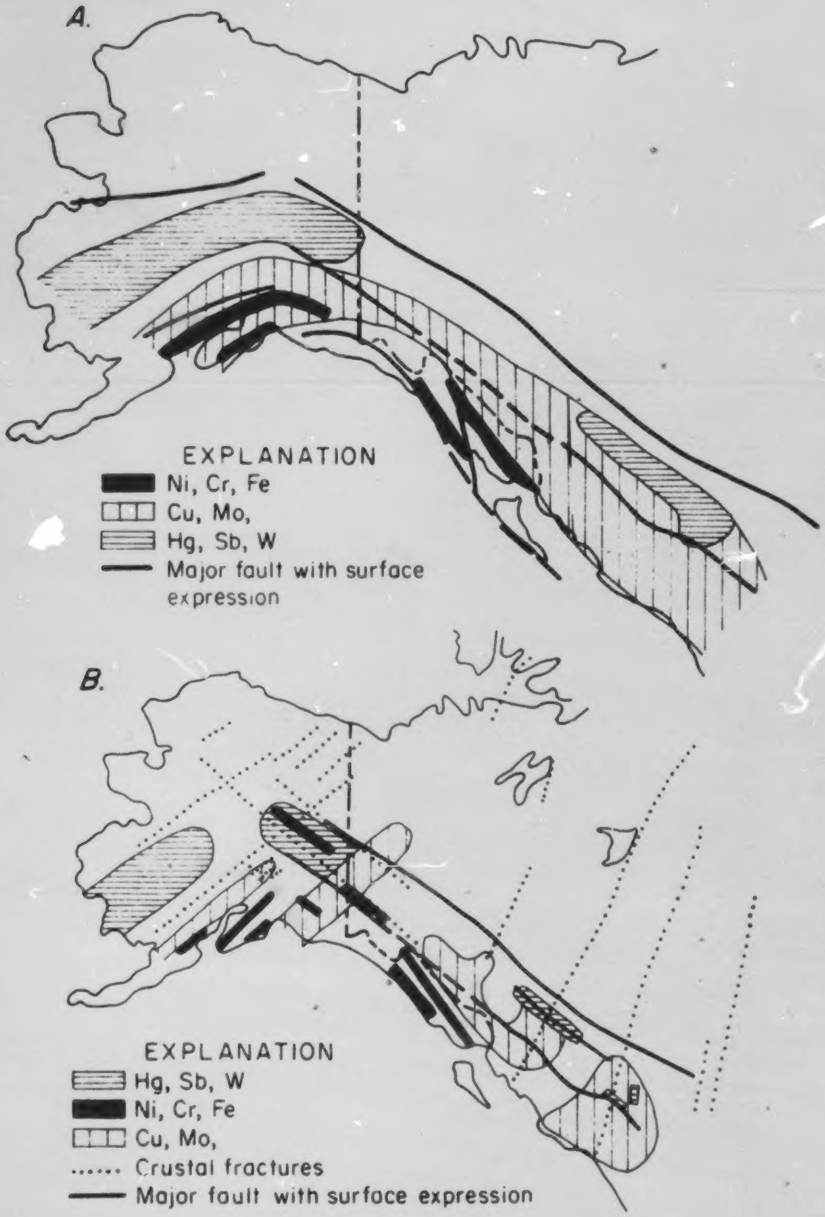
A.
EXPLANATION
▬ Ni, Cr, Fe
Cu, Mo,
Hg, Sb, W
— Major fault with surface expression
B.
EXPLANATION
Hg, Sb, W
▬ Ni, Cr, Fe
Cu, Mo,
...... Crustal fractures
— Major fault with surface expression

Fig. 3. Projected distribution of selected minerals in Alaska (after Lathram et al., 1973). A. Theory of association with geosynclinal evolution of western Cordillera. B. Theory of association with crustal fractures as observed in satellite imagery.

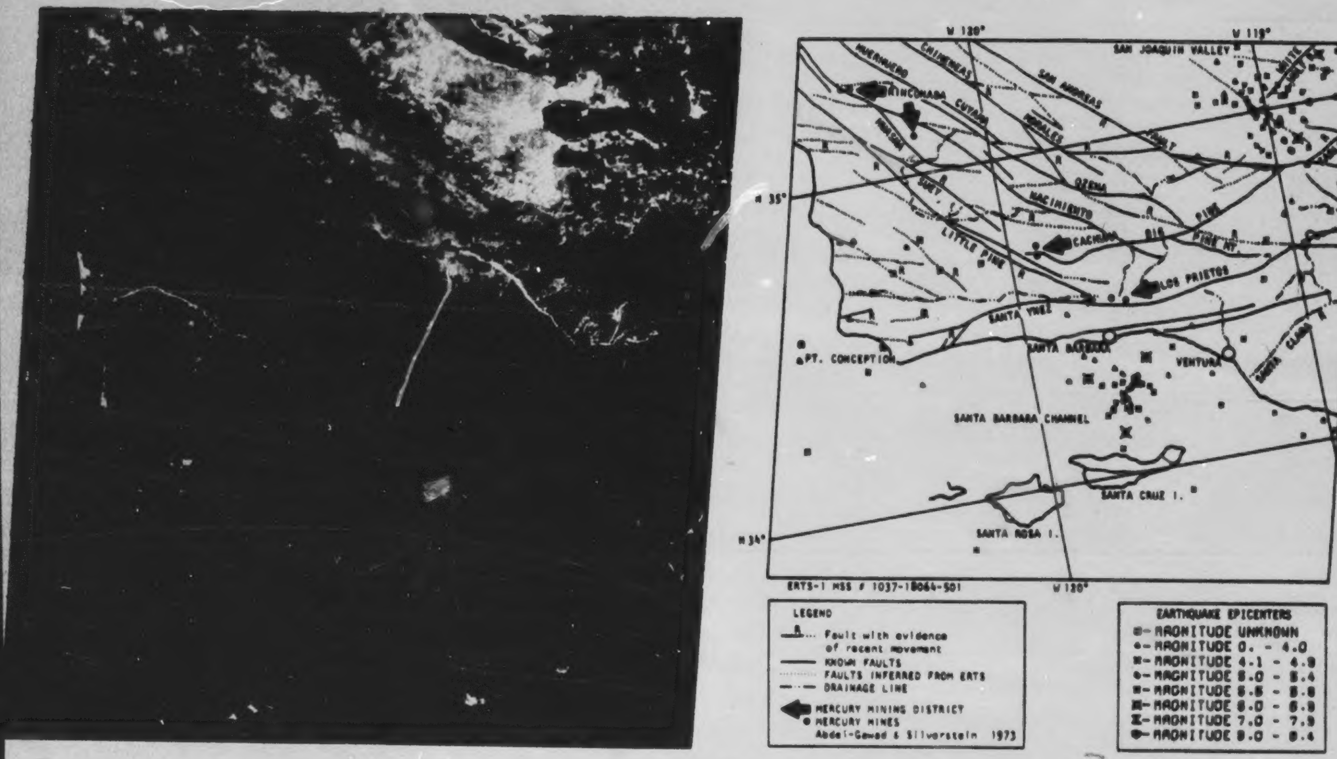
W 120°
W 119°
SAN JOAQUIN VALLEY
N 35°
RINCONADA
CHIMINEAS
SAN ANDREAS
MORALES
OZENA
NACIMIENTO
LITTLE PINE
CACHUMA
BIG PINE
PINE MT
LOS PRIETOS
SANTA YNEZ
SANTA BARBARA
VENTURA
SANTA CLARA R.
PT. CONCEPTION
SANTA BARBARA CHANNEL
SANTA CRUZ I.
SANTA ROSA I.
N 34°
ERTS-1 MSS # 1037-18064-501
LEGEND
Fault with evidence of recent movement
KNOWN FAULTS
FAULTS INFERRED FROM ERTS
DRAINAGE LINE
MERCURY MINING DISTRICT
MERCURY MINES
Abdel-Gawad & Silverstein 1973
EARTHQUAKE EPICENTERS
MAGNITUDE UNKNOWN
MAGNITUDE 0. - 4.0
MAGNITUDE 4.1 - 4.9
MAGNITUDE 5.0 - 5.4
MAGNITUDE 5.5 - 5.9
MAGNITUDE 6.0 - 6.9
MAGNITUDE 7.0 - 7.9
MAGNITUDE 8.0 - 8.4

Fig. 4. LANDSAT imagery of southern California and a plot of faults (after Abdel-Gawad and Silverstein, 1973).

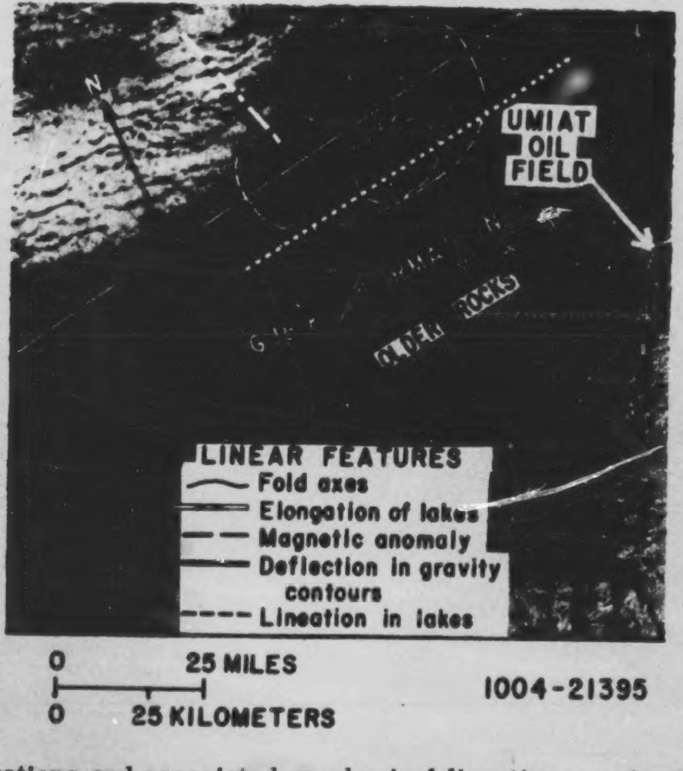
N
UMIAT OIL FIELD
OLDER ROCKS
LINEAR FEATURES
Fold axes
Elongation of lakes
Magnetic anomaly
Deflection in gravity contours
Lineation in lakes
0 25 MILES
0 25 KILOMETERS
1004-21395

Fig. 5. Lake orientations and associated geophysical lineations on the Alaskan Arctic Coastal Plain (after Lathram et al., 1973).

LANDSAT DATA

Vocabulary - Define the following terms in detail.

LANDSAT
Mosaic
ERTS
Geologists
Seismic
Erosion
Lineaments
Faults

Ni
Cr
Fe
Cu
Mo
Hg
Sb

Chemical Symbols

Questions - Answer the following inquiries in detail.

1. What user application does LANDSAT have?
2. How has LANDSAT been important to mineral and petroleum exploration?
3. How has LANDSAT assisted in the making of lineament maps?
4. The mosaic map was developed through LANDSAT. What are the implications of this map?
5. What minerals were discovered in Alaska through LANDSAT?

Discussion Topics

1. Why is ground truth necessary in geological LANDSAT data aquisition?
2. Did LANDSAT's imagery improve on old maps? How?

ACTIVE AND INACTIVE FAULTS IN SOUTHERN CALIFORNIA VIEWED FROM SKYLAB

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ABSTRACT

Repeated movement along active high-angle faults results in distinctive TOPOGRAPHIC features such as scarps, offset drainage, and depressions, and also impoundage of ground water. Many of these features are identifiable in Skylab photography of arid regions of southern California. The 190B camera is superior to the 190A camera for distinguishing active from inactive faults because the majority of the topographic features have a scale of meters to tens of meters requiring HIGH RESOLUTION. A northwestern extension of a fault in the San Andreas set, indicated by recent geophysical surveys in northwest Sonora, is postulated by the regional alignment of possible fault-controlled features. The suspected fault is covered by Holocene deposits, principally windblown sand, and therefore subsurface exploration would be necessary to verify its existence. A northwest trending tonal change in cultivated fields across Mexicali Valley is visible on Skylab photos. No surface evidence for faulting was observed; however, the linear may be caused by differences in soil conditions along an extension of a segment of the San Jacinto fault zone.

A number of prominent LINEARS in basement TERRANE of the Peninsular Ranges appear on Skylab images. In most cases they are represented by straight or gently curved valleys; however, detailed field investigations have shown that several of these linears mark previously unmapped faults which form two distinct fault sets; one set trends northeast, the other west-northwest. No indications of recent movement are present on these faults which are truncated by SEISMICALLY active, northwest trending fault zones such as the Elsinore and San Jacinto. Right-lateral separation is demonstrable on the northeast trending set. Left-lateral separation is possible but not definitely established on the west-northwest trending set. The two sets may represent CONJUGATE SHEARS that formed in response to an earlier stress system involving west-southwest, east-northeast crustal shortening. Field investigations have proven that a number of other linears are not due to faulting. They resulted from erosion along foliation or close-spaced joint sets, or are produced by the coincidental alignment of LINEAR segments of diverse origin. The combination of the SYNOPTIC view and the HIGH RESOLUTION of Skylab images has proved valuable in regional fault studies. Information on faults resulting from our investigation is applicable to land-use planning and the siting of engineered structures in southern California.

INTRODUCTION

Knowledge of the location and earthquake potential of faults is an essential input to land-use planning and the siting of critical engineered structures, such as nuclear power plants, dams, hospitals and schools. Earthquake damage to structures is related to earthquake magnitude, distance to the hypocenter, and local geologic conditions. A rough correlation between earthquake magnitude and fault length can be used to estimate the maximum credible earthquake, and the possibility of future movement can be predicted to some degree from the past history of movements. The human historic record is too short for estimating earthquake recurrence intervals for large earthquakes on active faults in California; therefore, the recent geologic history of movement should also be used. Inactive faults, as well as active faults, are unsuitable sites for dams and reservoirs and constitute a hazard to tunneling operations. Fault gouge and breccia are poor foundation materials, and fault zones commonly provide the passageway for large volumes of subsurface water.

In an accelerating effort to introduce geologic information into the land-use planning process, Federal and state geologic agencies, in cooperation with universities and engineering-geologic consulting firms, are preparing fault maps of California. Faults are being classified on the basis of their geologic history of movement (e.g. Jennings, 1973; Ziony et al, 1974). This paper describes the application of Skylab imagery, in conjunction with larger scale photography and field investigations, to the preparation of these maps. Specifically, the images are being utilized to assist in 1) distinguishing active from inactive faults (by recognizing indications of recent displacement), 2) determining the length of potentially active faults, 3) identifying previously unmapped faults (inactive as well as active), and 4) gaining additional information on regional tectonic history.

DETERMINATION OF FAULT ACTIVITY

It is generally assumed that future movement will occur on faults that have been active in the recent past. Movement in Holocene time (past 11,000 years) is a commonly accepted criterion for classifying a fault as active although faults showing displacement since late Quaternary time should probably also be considered active for some purposes (Wentworth and Yerkes, 1971). In addition to the historic record and stratigraphic relationships, certain topographic features are useful indicators of recent movement. These include scarps, benches, linear ridges, shutter ridges, linear valleys (in recent sediments), undrained depressions, ponded alluvium and offset drainage (Vedder and Wallace, 1970). Although their preservation will vary depending on climatic conditions and rock type, at most locations these features probably would be obliterated by erosion or deposition in 11,000 years. They need to be evaluated with care in order to differentiate them from fault-line scarps, linear valleys, notches and apparent offset streams (trellis drainage), all of which could have been formed along ancient faults by differential erosion.

Blockage of ground water in alluvial deposits by fault displacement can cause spring alignment oases and linear differences in vegetation or land use along or on opposite sides of a fault. Such features are useful in tracing faults through alluvium where other surface indications are absent. Alluvial deposits are commonly not well dated, but the uppermost layers of alluvium are usually considered to have been deposited in Holocene time; thus, surface evidence of ground water blockage is evidence that the fault is active.

The ability of the Skylab 190B camera to resolve these indicators is examined along the section of the Garlock fault shown on the index map (Fig. 1). Although movement on the Garlock fault has not occurred in historic time, it should be considered active because of physiographic evidence of recent displacement. The following features previously described by Clark (1973) are visible on the enlarged Skylab image (Fig. 2): depressions, linear valleys, linear ridges, shutter ridges and faceted ridges. Other features with relief on the order of one meter are not visible. Comparison with Clark's map indicates that scarps and ridges down to perhaps 5 meters or less in height can be seen when aided by shadow. Topographic indicators of recent faulting posses a wide range in scale; depressions may be measured in KILOMETERS and scarps in CENTIMETERS. But a large proportion of them fall into the range of meters to tens of meters and are, therefore, resolved by the 190B camera with an estimated spatial resolution of about 10 meters (ca. 30 feet). The 190A camera with a resolution of around 30 meters (ca. 100 feet) resolves a large percentage of these features, but is less suitable for this purpose.

Fig. 3 covers a segment of the Mesquite Lake fault, which is part of a northwest trending zone extending from the southern edge of the Mojave Desert almost to the Garlock fault (Hope, 1966). Bassett and Kupfer (1964) inferred right-slip on this fault from the orientation of drag folds in Pleistocene (?) sediments. Vegetation grows only on the south side of the fault where ground water has been impounded; a change in vegetation along the fault trace is clearly visible north of the town of Twentynine Palms (Fig. 4).

Segments of the Pinto Mountain fault are visible in the same image (Fig. 3). The east trending Pinto Mountain fault stretches over 50 kilometers (30 miles) from the San Andreas fault to Twentynine Palms, where it meets the Mesquite Lake fault in a structurally complex area (Hope, 1966). Recent activity is indicated by scarps across alluvial fans and a stand of palms growing along the fault at the Oasis of Mara; the seeps are produced by ground water blockage (Bassett and Kupfer, 1964).

The foregoing examples are high-angle faults with straight or gently curved traces. Repeated movements have produced large, distinctive topographic features. Thrust or reverse faults have more irregular traces, and mass movements on the upthrown block commonly obscure their traces. Such faults are not easily recognized on Skylab photos or even in conventional aerial photography.

SALTON TROUGH AREA

Photos of the Salton Trough between the Gulf of California and the Salton Sea taken from Skylab provide a remarkable overview which aids in the interpretation of the regional relationship between structural features. The structure of the Salton Trough is of considerable interest because of its geothermal resources, a proposed nuclear desalination plant near Yuma, Arizona, and a controversy concerning the southeastern extension of the San Andreas fault beyond the southeast end of the Salton Sea. Linears and other features which appear on the Skylab images southeast of the San Andreas fault, and strands of the San Jacinto fault, have been investigated. The areas covered by the individual Skylab images studied are outlined on Fig. 5, and the images are reproduced as Figs. 6 and 7.

SAN ANDREAS FAULT

The San Andreas fault, the major TECTONIC feature of California, extends for nearly 1000 KILOMETERS (600 miles) southeasterly from the Pacific Ocean near Point Arena to at least a point approximately midway along the eastern shore of the Salton Sea (Fig. 1). Southeast of the Salton Sea, surface evidence of faulting in late QUATERNARY sediments and seismic activity are lacking, and on the basis of subsurface investigations, Biehler et al (1964) conclude that a southeastern extension of the San Andreas fault can not be justified. Allen et al (1972) have suggested that the San Andreas fault is a right-lateral transform fault and that activity at the southeast end may terminate at a spreading center. The spreading center could lie between the San Andreas and San Jacinto faults beneath Quaternary volcanic rocks and geothermal anomalies on the southeast shore of the Salton Sea (Elders et al, 1972). According to this hypothesis, extensions of the fault to the southeast would have little or no horizontal displacement but would bring crust of different age and character into JUXTAPOSITION. Thus, abrupt differences in depth to basement could occur across southeastern extensions of the San Andreas fault zone. The eastern edge of the Salton Trough sedimentary basin is possibly delineated by such faults.

East of the Salton Trough, deposits similar or correlative to the Imperial Formation (Pliocene) are exposed at an altitude of about 320 meters (1050 feet). Near the center of Imperial Valley, these deposits were not penetrated in a well bottoming at a depth of 4098 meters (13,443 feet) (Dutcher et al, 1972). The required vertical offset could be explained by a fault interpreted from geophysical surveys near the eastern margin of the Sand Hills (Kovach et al, 1962). The Sand Hills fault has been aligned with the Algadones fault southeast of Yuma, Arizona (Mattick et al, 1973). However, the Algadones fault cannot delineate the eastern margin of the Salton Trough in Sonora, Mexico, because a southeastern extension would lie east of exposures of basement rocks of possible Precambrian age in Sierra del Rosario (R. Merriam, personal communication).

Gravity and aeromagnetic data suggest 3 kilometers (2 miles) vertical separation at the top of basement rocks along a fault between sediments of the Salton Trough and basement rock exposed to the northeast in Sierra del Rosario (Sumner, 1972). Between the Salton Sea and Gulf of California, shifting sands and river flood plain deposits obscure any direct surface indications of faulting along the northeast edge of the Salton Trough. However, physiographic features appearing on Skylab imagery may be indicative of faulting along this trend. A prominent dark spot appears on the Skylab image (Fig. 6) on the approximate surface trace of the fault identified by Sumner. The dark spot is a lake (R. Merriam, personal communication) which, in this arid region, could be due to impoundage of ground water on the northeast side of a fault.

To the northwest, a remarkably straight tonal difference is located near the edge of the Sand Hills. The slightly darker tone on the northeast side is the result of denser vegetation which may be due to impoundage of ground water on the upthrown side of a fault. We are unaware of any water well data which could test this hypothesis. A fault is suspected on the basis of a well drilled on the southwest margin of the dune field (S. L. Werner, personal communication). The well was drilled on a geothermal ANOMALY by the California Department of Water Resources, and silicified recent basin deposits were encountered (Werner and Olson, 1970). The relatively straight dune edge may be primarily wind controlled (Norris and Norris, 1961). However, the linear change in vegetation may contribute to the straightness, as the western edge of the dune field is much straighter than the eastern edge.

Approximately half way along the western edge of the Sand Hills, the dune field overlaps the line of vegetation. To the northwest, the suspected fault is aligned with the Hot Springs fault; however, it could join the Sand Hills fault as shown by Jennings (1973). Between the north end of the vegetation break and the Hot Springs fault, surficial evidence of faulting would be obscured by cultivated fields and leakage along the Coachells Branch of the All American Canal. The overview provided by Skylab images therefore aided in the interpretation of a possible fault in the San Andreas set by showing the regional alignment of fault indicators at an appropriate scale.

SAN JACINTO FAULT ZONE

The San Jacinto fault zone extends from near the San Andreas fault in the San Gabriel

Mountains and continues southeast approximately 500 kilometers (300 miles) to the Gulf of California as a zone of sub-parallel and branching faults up to 20 kilometers (12 miles) wide (Fig. 1). Two prominent LINEARS appear on the Skylab images of the Colorado Delta area (Fig. 6). The western linear in recent DELTAIC deposits corresponds to the segment of the San Jacinto fault believed to have been active in 1934 (Allen et al, 1965). The eastern linear appears as a straight, sharp boundary between deltaic deposits on the west and dune sand on the east. Merriam (1965) indicates that the southeast end of this linear is a fault and describes extensions of the San Jacinto fault zone to the southeast in Sonora.

To the northwest in Mexicali Valley, the fault traces are obscured by cultivated fields. However, an inferred northwest extension of the western linear passes through the Cerro Prieto geothermal field (De Anda and Parides, 1964); it is reasonable to assume that the geothermal activity is related to the fault zone. Northwest of the geothermal area, faint differences in the tone of cultivated fields south of Mexicali can be seen across a line along the same trend (Figs. 5 and 7). No additional evidence concerning the origin of this linear was found during a field reconnaissance, but variations in the tone of the cultivated fields could be related to subtle differences in the soil. The lake sediments beneath Mexicali Valley are primarily interbedded silt and clay. Because of better drainage, silt is preferable for crops. Silt and clay juxtaposed along a fault could be reflected in different crops or land use.

The tonal difference cannot be traced northwest of a point 6 kilometers (4 miles) south of the international border, but a continuation of the same trend lines up with a fairly straight segment of the New River. Exposures along the New River north of the border were examined, but no evidence of faulting was observed. If a fault along this trend curves slightly and is situated west of the New River, it would be aligned with a queried fault in the San Jacinto fault zone shown by Jennings (1973).

PREVIOUSLY UNMAPPED FAULTS IN BASEMENT TERRANE OF THE PENINSULAR RANGES

The CRYSTALLINE basement terrane of the Peninsular Ranges in southwestern California is composed of late MESOZOIC PLUTONIC rocks and associated roof pendants of METAMORPHOSED PALEOZOIC and MESOZOIC rocks (Jahns, 1954). Northwest trending faults of the San Andreas set (Hill, 1965), notably the San Jacinto and Elsinore fault zones, dominate the structure of the Peninsular Ranges. Recently acquired small-scale images from Skylab and LANDSAT spacecraft, as well as larger scale color aerial photos from RB-57 and U-2 aircraft, have provided a new look at this region. Lowman (1969) originally pointed out that unmapped northeast trending linears, expressed primarily by persistent valleys, are prominent on Gemini and Apollo photographs of the Peninsular Ranges of southwestern California. These features and the San Jacinto, Elsinore and other northwest trending faults are apparent in the Skylab image reproduced in Fig. 8. A number of west-northwest linears and one north-south linear are also visible. As shown on Fig. 9, some of these linears have been previously mapped as faults, but many others have not.

The mapping and compilations of Merriam (1955, 1958), Larsen (1948), Everhart (1951), Rogers (1965), Strand (1967), Gastil et al (1971), Weber (1963), and Jenings (1973) have been invaluable in our studies. However, most of the previous mapping has been at reconnaissance scales (1:62,500 or smaller) and earlier studies were without the benefit of aerial photography. Consequently, it is not surprising that some of the faults recognized in our investigation are not shown on existing geologic maps.

Using the perspective provided by small-scale imagery from the Skylab and LANDSAT spacecraft, attention was focused on persistent linears which were heretofore unmapped because they were not obvious in larger scale photography or on the ground. Aided by large-scale aerial photos, field investigations were accomplished to determine the nature of the linears not explained by previous geologic mapping (see Merifield and Lamar, 1974). Several of the features have been identified as faults by displaced contacts and well-developed breccia zones and slickensided shear surfaces parallel to the linear. Field work is hampered by the dense growth of CHAPARRAL which denies access to large areas. Moreover, displacements within the basement terrane are difficult to establish owing to gradational contacts and zones of mixed rocks.

The northeast trending San Ysidro Creek fault was first recognized as a prominent 7 kilometer (4 mile) long linear on satellite images by Lowman (1969). Discovery of exposures of gouge up to 7 meters (20 feet) wide with straited shear surfaces parallel to the linear demonstrates the existence of the fault. Data are insufficient to determine the slip direction on the San Ysidro Creek fault, but striations on shear surfaces suggest predominantly horizontal (strike-slip) movement. The ends of the San Ysidro Creek fault appear to terminate against northwest trending faults.

The northeast trending San Diego River Valley southwest of the Elsinore fault forms a 30 kilometer (20 mile) long linear separated 10 kilometers (6 miles) from the southwest end of the San Ysidro Creek fault. Although the San Diego River linear and San Ysidro Creek fault are approximately aligned, Skylab imagery, as well as larger scale air photographs, clearly show that these features do not connect. The northeast end of the San Diego River linear appears to abut the Elsinore fault.

Some previous maps (Sauer, 1929; Miller, 1935; California Department of Water Resources, 1967; Jennings 1973) show a fault or inferred fault along The San Diego River, while others (Everhart, 1951; Merriam, 1958; Strand, 1962; Rogers, 1965; Fitzurka, 1968) do not. None of the previous maps or reports which indicate a fault describe any field observations of fault zone exposures or offset rock contacts.

In a detailed study along a segment of the river, Fitzurka (1968) found a right-separation of contacts between Julian Schist and PLUTONIC rocks of 300 to 600 meters (1000 to 2000 feet). A fault along the river in the area mapped by Fitzurka would be obscured by alluvium, and he reported no direct evidence of faulting. Our field work substantiated the apparent separation observed by Fitzurka and also revealed a probable 420 meter (1400 feet) right-separation of a schist body within quartz diorite along the same trend to the northeast. An en ECHELON pattern of zones of sheared and altered breccias and alignments of straight canyon segments saddles and benches was also discovered along the river valley. The orientation of the en echelon pattern is consistent with right-slip along a shear zone.

One of the most prominent linears seen on satellite imagery stretches for 20 kilometers (12 miles) in a north-northeast direction through Thing Valley in southeastern San Diego County. BRECCIA, FAULT GOUGE and slickensided shear surfaces were discovered along the linear. One hundred meters (330 feet) of right separation was measured on the fault at the southwest end of Thing Valley, and field work and study of large-scale air photos suggest as much as 1 kilometer (0.6 mile) of right-separation of mixed metamorphic and igneous rocks at the northeast end of Thing Valley. The latter separation, however, may be explained at least in part by contacts curving nearly parallel into the fault.

Although the exact relationships are obscured by alluvium, the north end of the Thing Valley fault south of Agua Caliente Hot Springs appears to be displaced 700-1300 meters (2300-4300 feet) in a right-lateral sense by the south branch of the Elsinore fault, as mapped by Merriam (1955) and Buttram (1962). It is impossible to prove that the Thing Valley fault was ever continuous across the Elsinore fault, but previous alignment is suggested by similar attitudes of the fault segments (Merifield and Lamar, 1974). The north end of the Thing Valley fault abuts the north branch of the Elsinore fault at Agua Calinete Hot Springs; a concentration of breccia at the fault intersection may provide a conduit for the hot water.

In addition to northeast trending faults, several west-northwest to east-west faults have been identified. The most prominent of these was mapped by Weber (1963) over 40 kilometers (24 miles) in a west-northwest direction from El Cajon to Campo (shown as Barrett Lake fault on Figs. 8 and 9). Our attention was drawn to additional linears of this trend by studies of Skylab, LANDSAT and RB-57 photos. Fault breccia and slickensided shear surfaces have been found along two of these linears which have been referred to as the Potrero and Ramona faults (Merifield and Lamar, 1974). Because of the lack of distinctive contacts between rock units, the amount and sense of displacement on these faults is indeterminant. An apparent 120 meter (370 foot) left-separation of 40° northeast dipping flows in the Santiago Peak volcanics was observed at the eastern end of the east-west trending Otay Mountain linear. The exposures are not adequate to prove that the separation is due to faulting, and no other evidence of faulting was observed along this linear.

A north-south trending linear was studied and named the Chariot Canyon fault by Allison (1974a, 1974b), who reports 8 kilometers (5 miles) of right-separation based on the distribution of Julian Schist and plutonic rocks. Our examination of a number of exposures in Chariot Canyon did not reveal a single fault separating Julian Schist on the west from granitic rocks on the east, but a broad shear zone appears to occupy the width of the canyon. Steeply dipping SLICKENSIDED SHEAR SURFACES were observed to strike between north-south and N30°W. The foliation in schist and gneiss is locally undulatory, but has a general strike conformable with the shear surfaces and the trend of the canyon. Several other linears which show no evidence of faulting were investigated and are indicated on Fig. 9. In some cases, the exposures were sufficient to make us reasonably certain that the linear is due to erosion along foliation (Henderson Canyon linear) or joints (Sutherland Reservoir linear). Intrusive contacts along the Sweetwater River in Cuyamaca Rancho Park curve to the right as they cross the river valley, and no distinct break is evident. Thus, the Sweetwater River linear (Fig. 9) corresponds to the axis of a small flexure or perhaps shear (slip) fold. The Witch Creek linear is shown as a fault by Jennings (1973); our study indicates that a contact in basement rock is not displaced along this feature, and no evidence of faulting was found. The origin of other linears could not be established with certainty because of the lack of exposures and mappable contacts.

Of particular interest is the relationship of the northeast and west-northwest trending faults which we investigated, to the northwest trending faults of the San Andreas set. If the northeast trending faults form a conjugate shear system with the presently active northwest trending right-slip faults, the northeast trending faults would have to be left-slip. However, a right-slip component is probable on the Thing Valley and San Diego River faults. Also, the northeast and west-northwest trending faults are restricted to pre-Tertiary rocks and nowhere cut the northwest set.

It is possible that the northeast and west-northwest sets were formed by an older stress system, unrelated to the presently active system. East-northeast, west-southwest crustal shortening is consistent with the fault pattern and probable right-separation on the Thing Valley and San Diego River faults. No conclusive evidence of the slip direction on the west-northwest trending faults has been found, although left separation on the east trending Otay Mountain linear is possible. Data concerning slip directions on the faults studied, therefore, are not adequate to prove this hypothesis. However, on the basis of north-south trending thrust faults and MYLONITIC zones, Sharp (1968) has also suggested an earlier period (Middle Cretaceous to Eocene) of east-west crustal shortening in the eastern Peninsular Ranges. The plate Tectonic model of a subduction zone parallel to the continental margin during the Mesozoic (Hamilton, 1969; Hill, 1971) is also consistent with earlier east-west crustal shortening.

CONCLUSIONS

The following conclusions are indicated from our study: (1) In areas such as the basement terrane of the Peninsular Ranges, where most of the mapping has been reconnaissance or accomplished decades ago without the aid of aerial photography, Skylab imagery provides an efficient means of focusing on potential faults and planning larger scale surveys. Several unreported faults have been found during our investigation. (2) Prominent photo linears result from erosion along foliation and jointing as well as faults. The coincidental alignment of unrelated features may also give the appearance of faults. Detailed field investigations are required to establish the origin of any linears. (3) Topographic indicators of movement on recently active, high-angle faults are resolved by the 190B camera, which is superior to the 190A camera for this purpose. The somewhat smaller coverage of the 190B camera is not a serious drawback. The critical indicators of faulting are topographic, and the multispectral capability of the 190A camera has not played a significant role in these investigations. (4) The perspective afforded by Skylab enables fault patterns to be viewed in a single image; this is useful in understanding regional relationships. The truncation of the east-west and northeast trending fault sets by the active northwest trending right-slip faults in the Peninsular Ranges is evident in Skylab photos. This broad perspective has also led to hypotheses for an extension of the San Jacinto fault across Mexicali Valley and the continuation of a fault forming the northeastern border of the Salton Trough.

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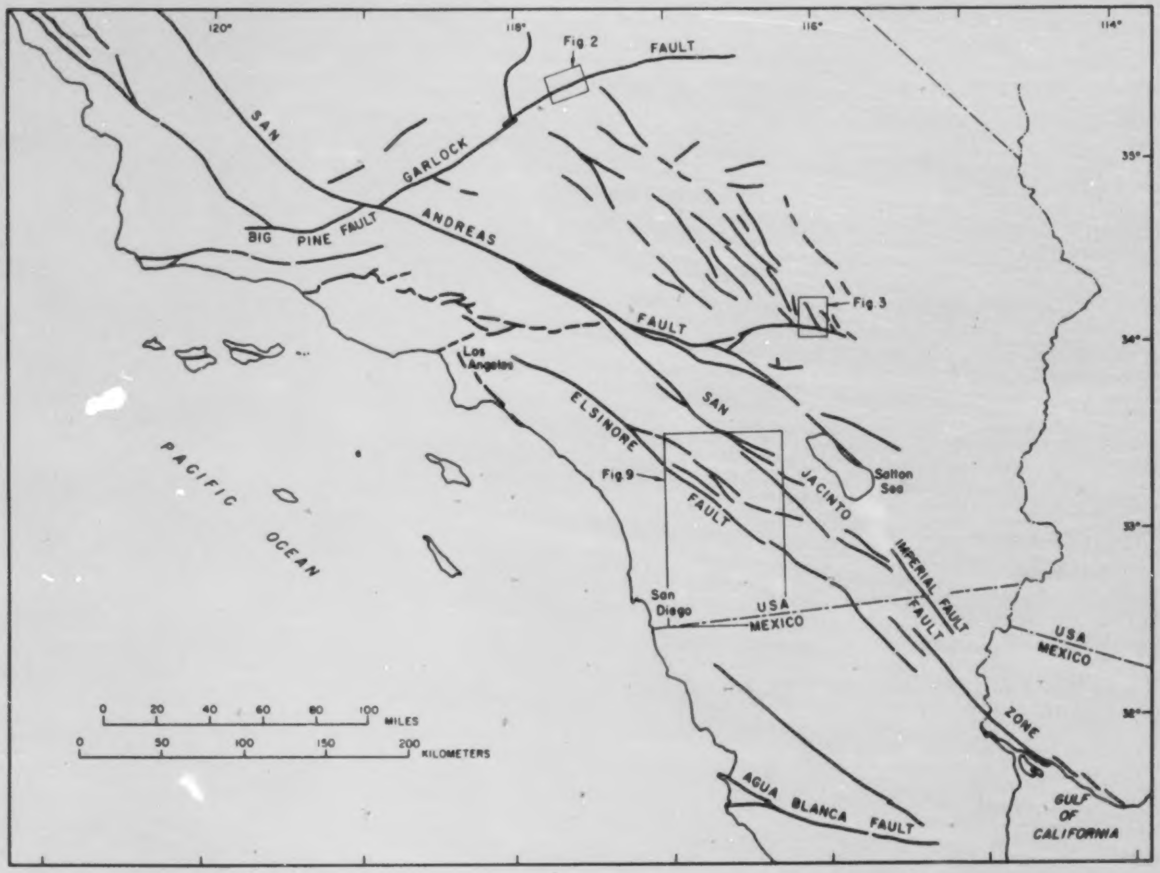
120°
118°
116°
114°
35°
34°
33°
32°
Fig 2
FAULT
SAN
GARLOCK
BIG PINE FAULT
ANDREAS
FAULT
Fig 3
Los Angeles
SAN
ELSINORE
JACINTO
Salton Sea
Fig 9
FAULT
PACIFIC OCEAN
IMPERIAL FAULT
FAULT
San Diego
USA
MEXICO
USA
MEXICO
ZONE
0 20 40 60 80 100 MILES
0 50 100 150 200 KILOMETERS
AGUA BLANCA FAULT
GULF OF CALIFORNIA

Fig. 1. Index map showing major faults and areas studied, redrawn from Proctor (1973).

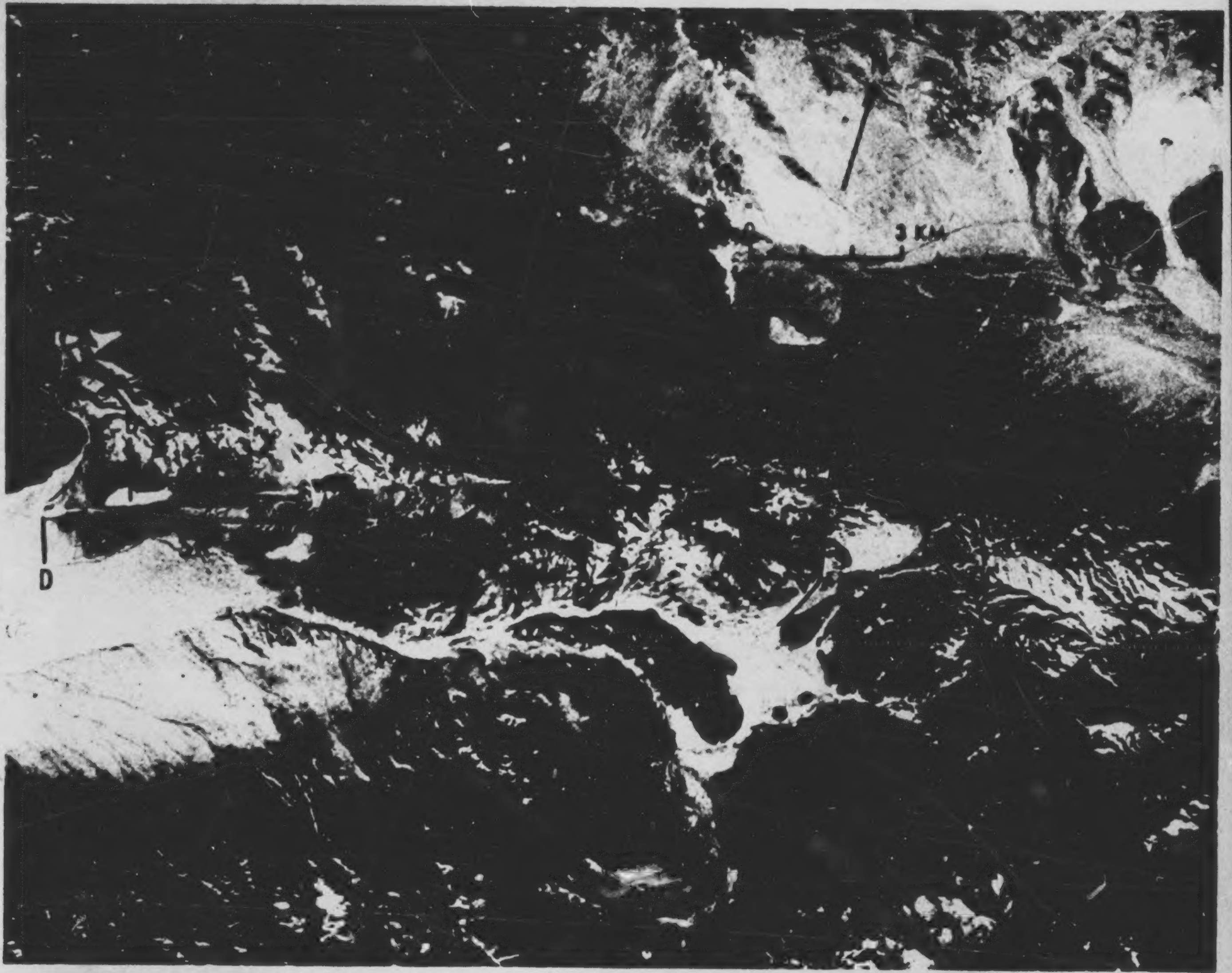

Fig. 2. Section of the Garlock fault south of Ridgecrest (see Fig. 1 for location). Enlargement of a portion of Skylab 4, 190B camera, Roll 92, Frame 347 (original in natural color). Legend: D, depression; SR, shutter ridge; OC, offset channel; LR, linear ridge, LV; linear valley, FR, faceted ridges.

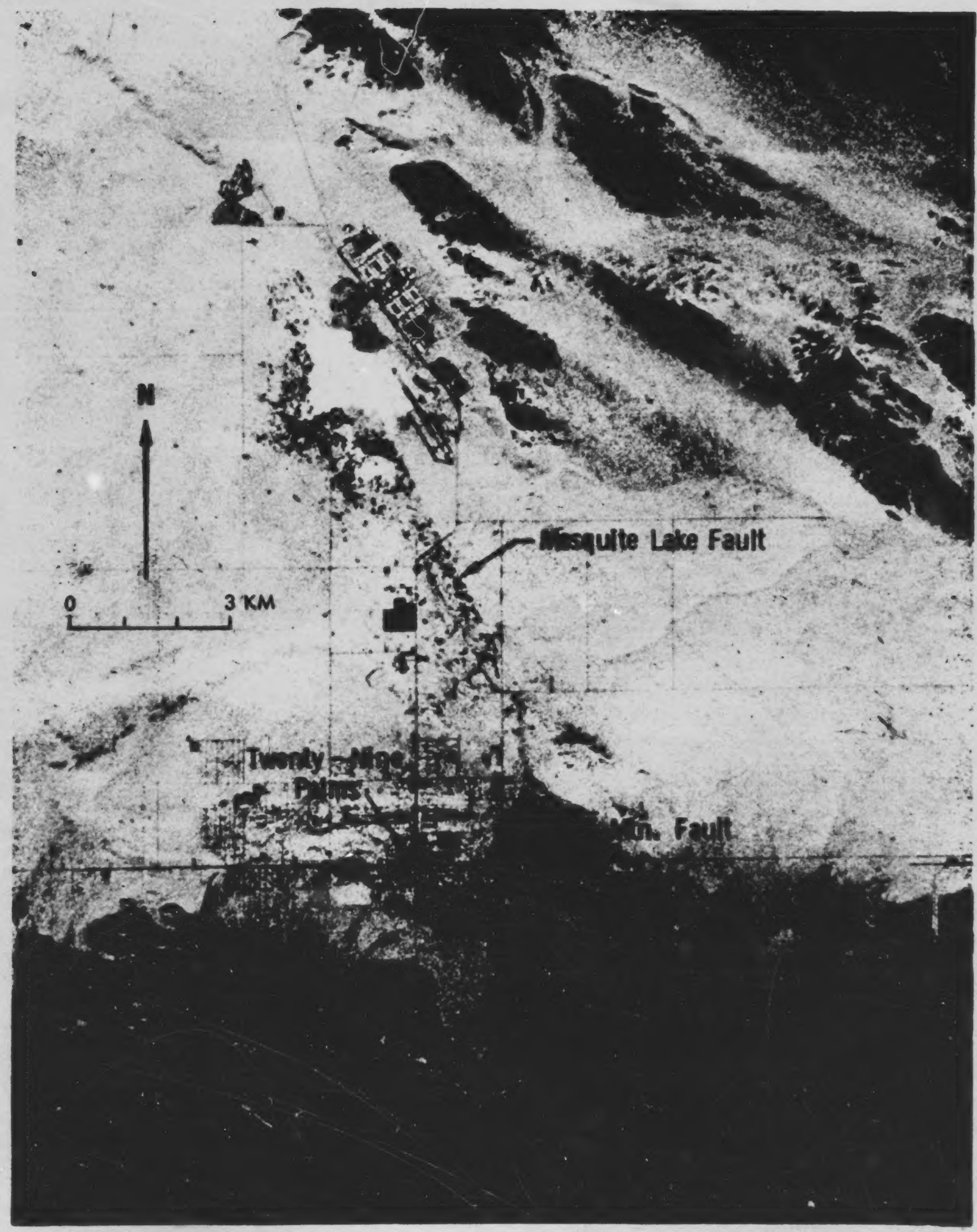
N
0
3 KM
Mesquite Lake Fault
Twenty-Nine Palms
Mtn. Fault

Fig. 3 - Mesquite Lake and Pinto Mountain faults near Twentynine Palms (see Fig. 1 for location). Enlargement of a portion of Skylab 4, 190B camera, Roll 92, Frame 351 (original in natural color).

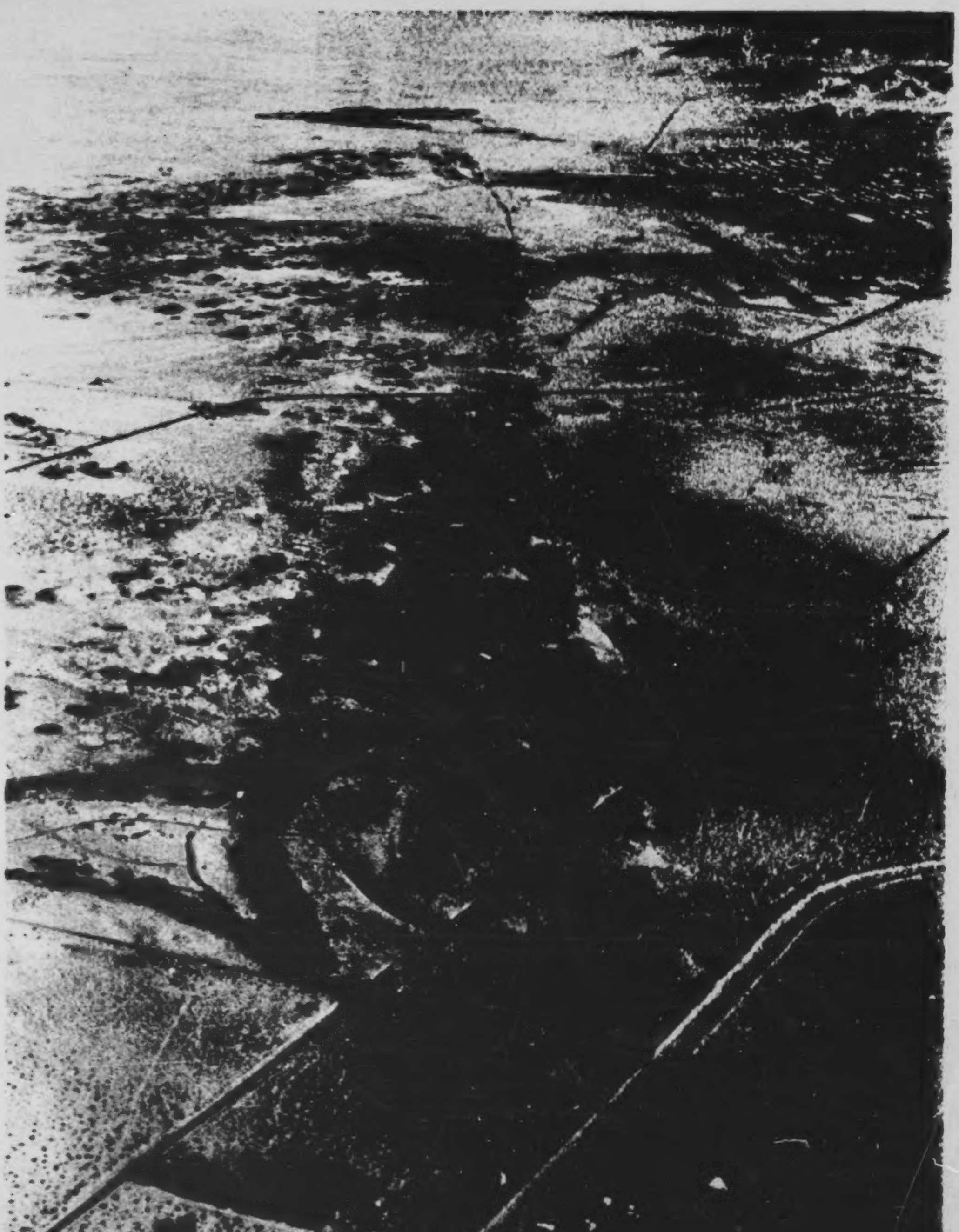

Figure 4. - Low-altitude aerial view looking northwest along the Mesquite Lake fault.

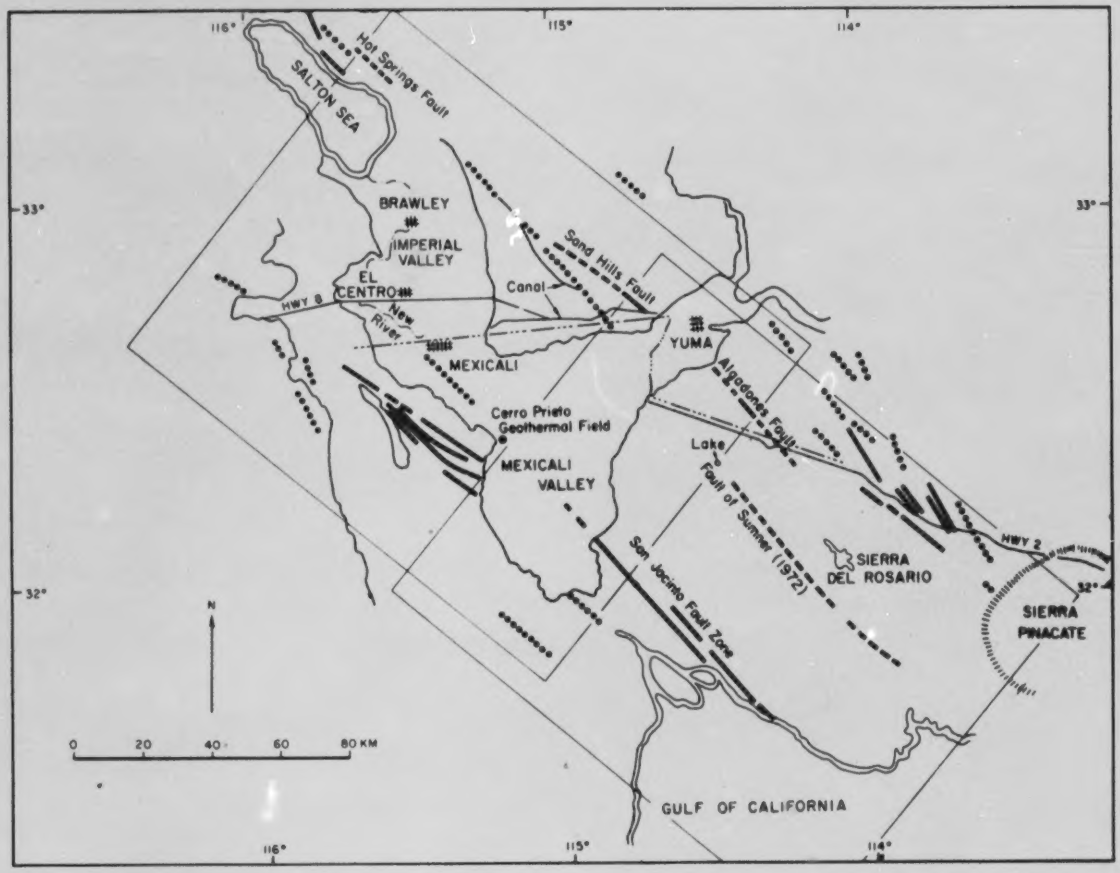
116°
115°
114°
33°
32°
Hot Springs Fault
SALTON SEA
BRAWLEY
IMPERIAL VALLEY
Sand Hills Fault
EL CENTRO
HWY 8
Canal
New River
YUMA
MEXICALI
Algodones Fault
Cerro Prieto Geothermal Field
Lake
MEXICALI VALLEY
Fault of Summer (1972)
SIERRA DEL ROSARIO
HWY 2
San Jacinto Fault Zone
SIERRA PINACATE
N
0 20 40 60 80 KM
GULF OF CALIFORNIA

Fig. 5. Location map, Salton Trough and vicinity. Legend: Heavy solid lines, mapped faults visible in Skylab photos; heavy short dashes, covered faults located primarily by geophysical surveys; dotted lines, photo linears of unknown origin.

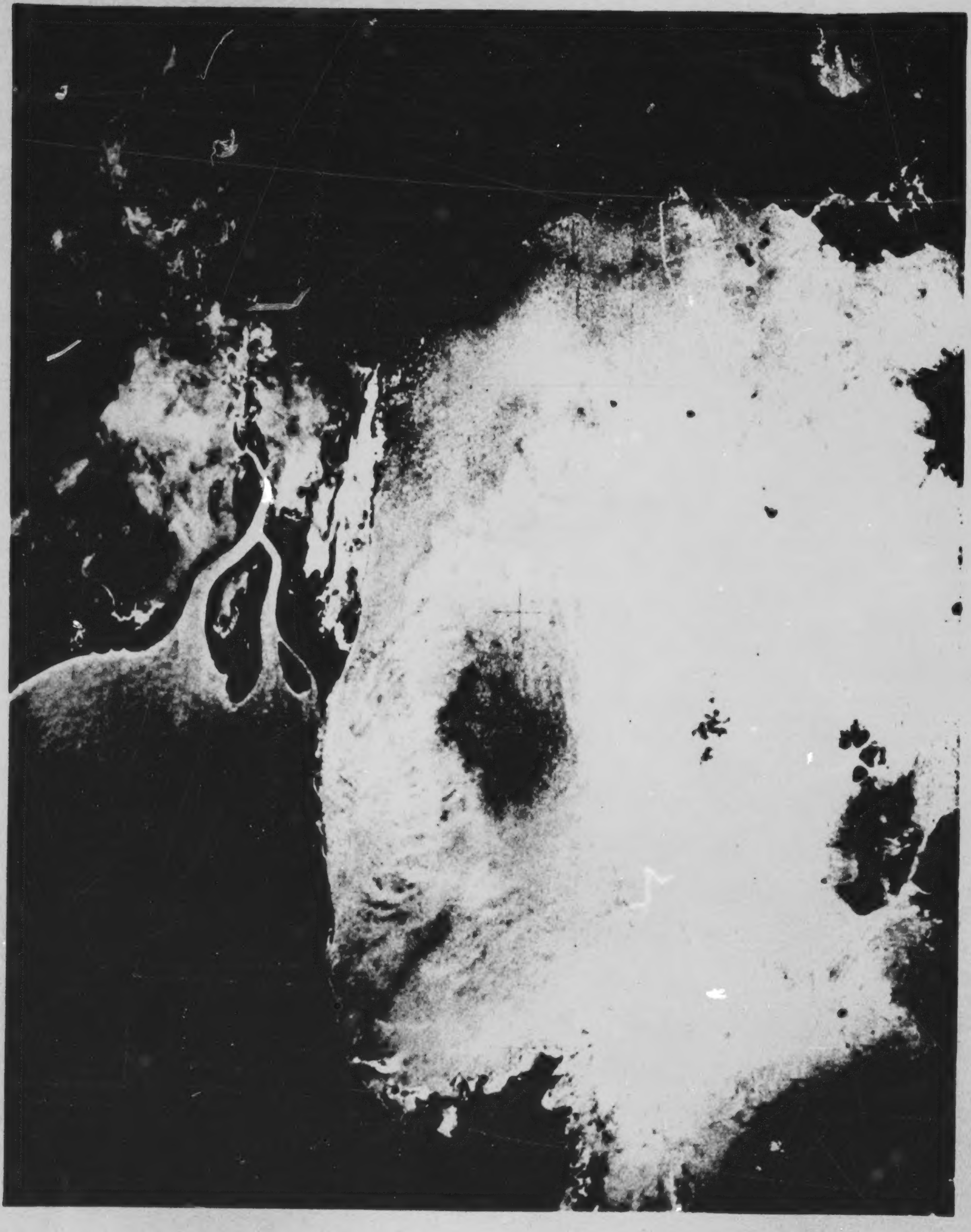

Fig. 6 - Colorado River Delta, Skylab 2, 190A camera, Roll 2, Frame 135 (original in natural color).

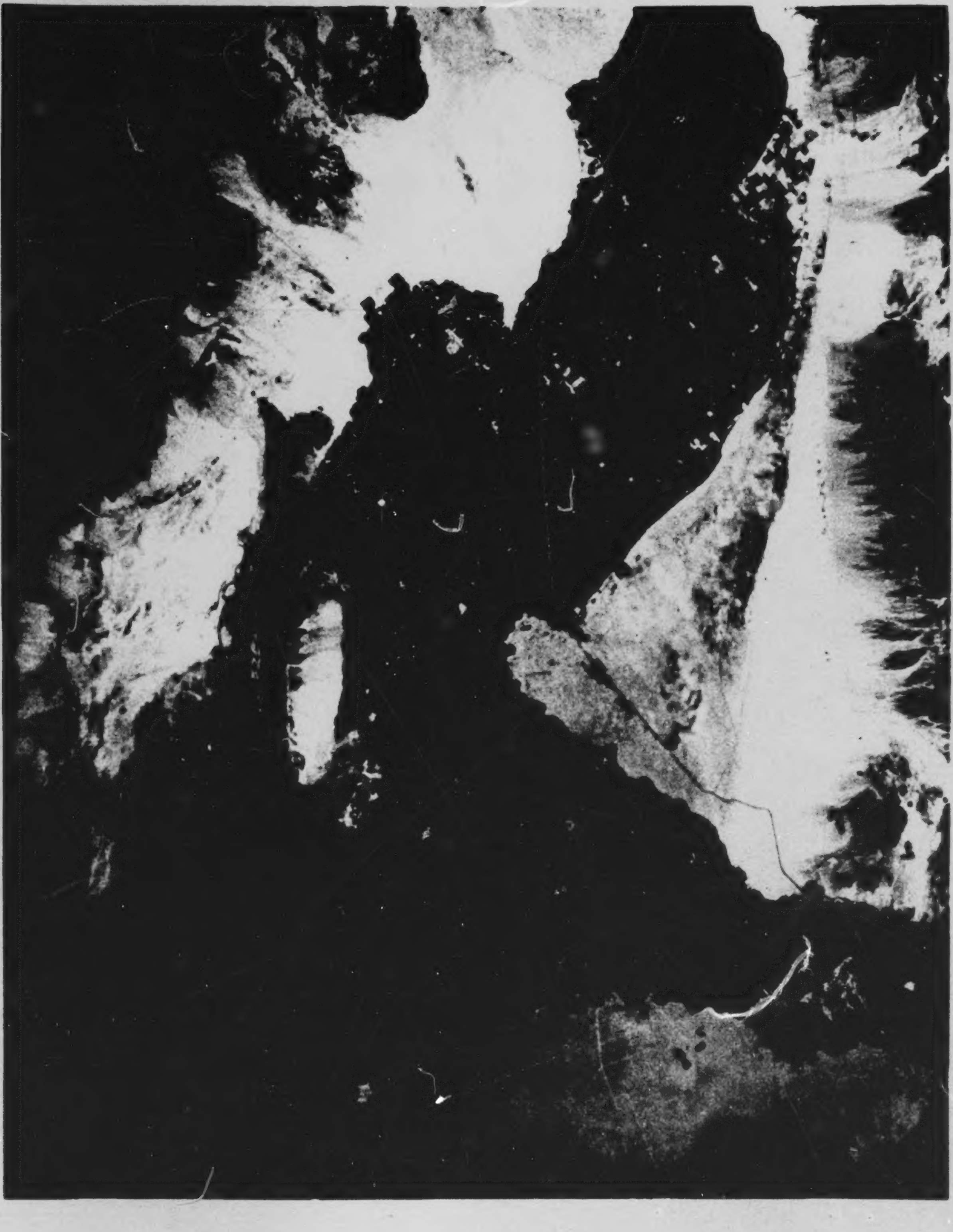

Fig. 7 - Eastern edge of Salton Trough, California and Sonora, Mexico, Skylab 2, 190A camera, Roll 4, Frame 133 (original in natural color).

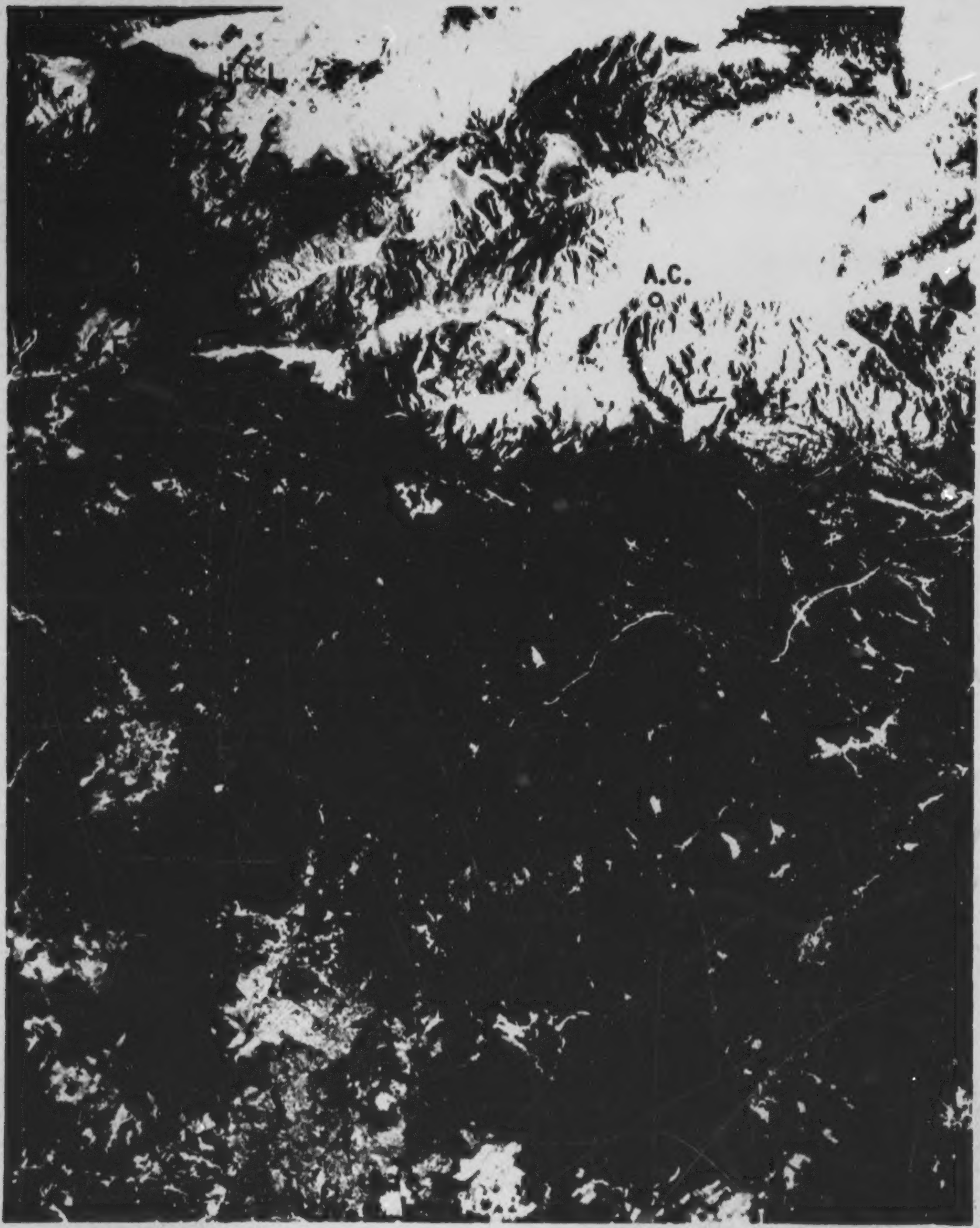

Fig. 8 - Peninsular Ranges, southwestern California, portion of Skylab 3, 190B camera, Roll 57, Frame 111. See Fig. 9 for location of individual features. Abbreviations: A.C., Agua Caliente Hot Springs; B.L.F., Barrett Lake fault; C.C.F., Chariot Canyon fault; E.F., Elsinore fault, H.C.L., Henderson Canyon linear; L.H., Lake Henshaw; O.M.F. Otay Mountain fault; P.F. Potrero fault; S.D.R.F., San Diego River fault; S.R.L., Sutherland Reservoir linear; SW.R.L., Sweetwater River linear; S.Y.C.F., San Ysidro Creek fault; T.V.F., Thing Valley fault.

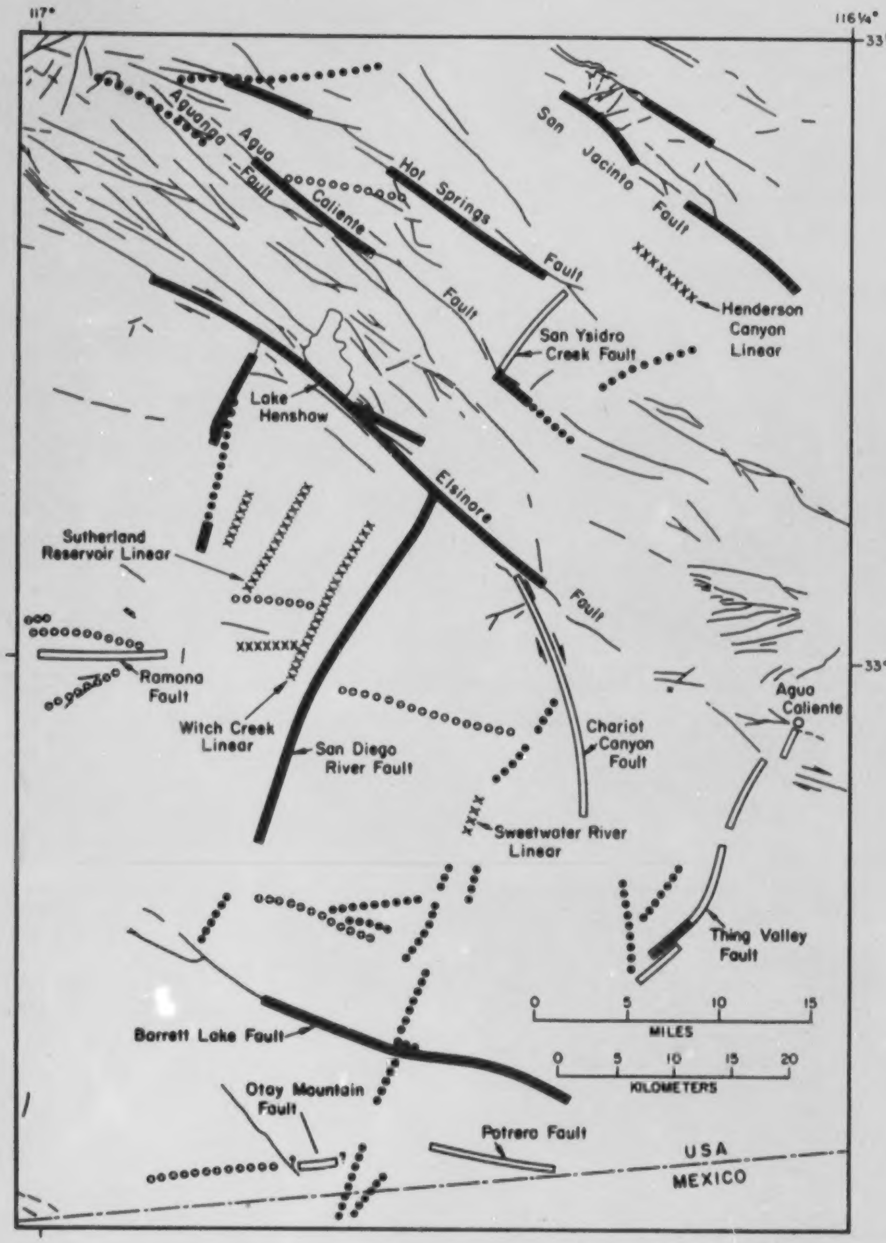
117°
116¼°
33½°
33°
Aguanga Fault
Agua Caliente Fault
Hot Springs Fault
San Jacinto Fault
Henderson Canyon Linear
San Ysidro Creek Fault
Lake Henshaw
Elsinore Fault
Sutherland Reservoir Linear
Ramona Fault
Witch Creek Linear
San Diego River Fault
Chariot Canyon Fault
Agua Caliente
Sweetwater River Linear
Thing Valley Fault
0 5 10 15
MILES
0 5 10 15 20
KILOMETERS
Barrett Lake Fault
Otay Mountain Fault
Potrero Fault
USA
MEXICO

Fig. 9 - Faults and linears visible on Skylab photo in Fig. 8, southwestern California. Solid lines, faults shown by Strand (1962), Rogers (1965), or Jennings (1973); heavy lines, faults visible on satellite images; light lines, faults not visible; open lines, previously unmapped faults. Dotted lines, linears of unknown character; solid dots, no field investigation; open dots, field investigation but exposures not adequate to determine origin, XXX, linears not due to faulting.

SOUTHERN CALIFORNIA FAULTS

Vocabulary - Define the following terms in detail.

- Offset drainage
- Scarps
- Fault zone
- Linears
- Shears
- Earthquake magnitude
- Gouge
- Breccia
- Geothermal
- Mesozoic
- Stratigraphic
- Topographic
- Benches
- Shutter ridges
- Alluvium
- Spatial resolution
- Tectonic
- Quaternary
- San Andreas
- Holocene

Questions - Answer the following inquiries in detail.

1. How was Skylab data acquisition utilized to identify linears?
2. Explain the physical considerations of the land when determining the location of any man made structure in relation to faults.
3. What were the applications of Skylab data in relation to images?
4. Discuss the historical references used when explaining future fault improvements.
5. In detail, explain the Mesquite Lake Fault and the Garlock Fault as examples of high angle faults?
6. Why is the Salton Trough area important to geothermal research?
7. What is the relationship of the San Andreas Fault to the Salton Sea?
8. Why is geothermal activity related to the San Jacinto Fault Zone?
9. How did Skylab and LANDSAT identify other linears? Which new linears did they find?
10. What conclusions did the researchers reach and why did they come to these conclusions as related to data acquisition?

Discussion Topics

1. Why is fault monitoring important to the residents of California?
2. How did LANDSAT assist in fault line discoveries?

OPTICAL DATA PROCESSING AND PROJECTED APPLICATIONS OF THE ERTS-1 IMAGERY COVERING THE 1973 MISSISSIPPI RIVER VALLEY FLOODS

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U.S. Geological Survey

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ABSTRACT

Flooding along the Mississippi River and some of its tributaries was detected by the multispectral scanner (MSS) on the Earth Resources Technology Satellite (ERTS-1) on at least three orbits during the spring of 1973. The ERTS data provided the first opportunity for mapping the regional extent of flooding at the time of the imagery. Special optical data processing techniques were used to produce a variety of multispectral color composites enhancing flood-plain details. One of these, a 2-color composite of near infrared bands 6 and 7, was enlarged and registered to 1:250,000-scale topographic maps and used as the basis for preparation of flood image maps. Two specially filtered 3-color composites of MSS bands 5, 6, and 7 and 4, 5, and 7 were prepared to aid in the interpretation of the data. The extent of the flooding was vividly depicted on a single image by 2-color temporal composites produced on the additive-color viewer using band 7 flood data superimposed on pre-flood band 7 images. On May 24, when the flood-waters at St. Louis receded to bankfull stage, imagery was again obtained by ERTS. Analysis of temporal data composites of the pre-flood and post-flood band 7 images indicate that changes in surface reflectance characteristics caused by the flooding can be delineated, thus making it possible to map the overall area flooded without the necessity of a real-time system to track and image the peak flood waves. Regional planning and disaster relief agencies such as the Corps of Engineers, Office of Emergency Preparedness, Soil Conservation Service, interstate river basin commissions and state agencies, as well as private lending and insurance institutions, have indicated strong potential applications for ERTS image-maps of flood-prone areas.

INTRODUCTION

During the spring of 1973, the Mississippi River Valley experienced some of the most disastrous flooding in recorded history. Tremendous areas of lowland were inundated along the Mississippi River main stem and along a number of major tributaries between St. Louis and the mouth of the river below New Orleans. At St. Louis, an all-time high flood crest of 43.3 feet was recorded on April 28, 1973, exceeding the previous record of 43 feet recorded in April 1785. Flood stage, which is 30 feet at St. Louis, was reached on March 10. The river remained above flood state at St. Louis for 76 days until it finally receded to to bankfull stage on May 24. Hydrographs of the river stages at St. Louis, Memphis, Vicksburg, and Baton Rouge are shown in Figure 1.

Flood mapping, by conventional methods, the techniques of which are well established and understood, is a time-consuming and expensive procedure. Traditionally, either ground surveys or black and white panchromatic photography has been used as a basic tool in flood mapping. During the past several years, however, utilization of new techniques of remote sensing by aircraft- and spacecraft-borne sensors has been gaining increased attention. Myers, Waltz, and Smith (1972), delineated the area flooded by Rapid Creek at Rapid City, South Dakota, using color and color infrared aerial photography and thermal infrared aerial imagery. From some of the early data obtained by ERTS-1, Benson and Waltz (1973) delineated and measured an area inundated by a severe local rainstorm near Aberdeen, South Dakota. Hallberg, Hoyer, and Rango (1973) reported on the mapping of the Nishnabotna River flood in Iowa, employing ERTS data collected a week after the flood. They also assessed the use of color infrared photography versus traditional black and white panchromatic photography for flood mapping purposes and found the former to be highly superior. Morrison and Cooley (1973) mapped inundation limits of the Gila River flood in Arizona from ERTS imagery and obtained good agreement with maps prepared from aircraft photography and ground surveys.

Early in March, 1973, in anticipation of flooding along the Mississippi River, the U.S. Geological Survey made a special request to the National Aeronautics and Space Administration for data from subsequent passes of the first Earth Resources Technology Satellite (ERTS-1) over the Mississippi River Valley. Basically, it was desired to be able to map the extent of inundation as quickly as possible, and with a minimum amount of conventional ground observations. It was surmised that specially processed ERTS data could provide hydrologists with a powerful new technique to supplement established methods of flood mapping, for the first time making it possible to accurately map the extent of flooding over very large areas, and to optically depict the flooded area.

On March 31, 1973, ERTS-1 provided the first synoptic view of extensive flooding along two large reaches of the Mississippi River, between St. Louis, Missouri, and Natchez, Mississippi. On May 4 and 5, ERTS-1 sensors imaged a strip of the Mississippi River reaching from midway between St. Louis and Cairo, Illinois, to New Orleans and the Gulf of Mexico. The flood is depicted at its peak within the reach between Cairo and Memphis. The flood peaked at Cairo on May 4 at 14.7 feet above flood stage. Cloud cover over most of the Mississippi River Valley below St. Louis on March 30, April 17 and 18, and May 6 prevented consecutive-day coverage over the entire reach from St. Louis to the mouth of the river.

On May 24, 1973, the date that the Mississippi River receded to bankfull stage at St. Louis (Figure 1), ERTS-1 again obtained cloud-free multispectral imagery over the swath imaged on March 31, thus providing a data base for determining the feasibility of mapping the total area flooded employing post-flood data.

On April 12 a NASA U-2 aircraft photographed the floods along the Mississippi River below St. Louis from an altitude of about 20,000 m (65,000 feet) employing color infrared film. The photography makes it possible to compare the relative effectiveness of space-acquired imagery and high-altitude photography for regional mapping of flood conditions in major river basins.

OBJECTIVES AND SCOPE

The principal objectives of this study were to determine the feasibility of employing ERTS-1 multispectral scanner (MSS) data to:

- Delineate the regional extent of flooding at the instant the imagery was collected at a scale of 1:250,000. (This scale was selected inasmuch as the entire United States --and many international areas—are covered by topographic maps at the same scale.)
- Delineate areas of flooding using post-flood data.
- Develop a methodology to enhance ERTS imagery of flood areas to show maximum detail in the flood plain and contrast with adjoining areas.
- Develop techniques of rapidly and accurately mapping large floods and flood-prone areas any place in the world with a minimum of ground truth.

This study was limited to analysis of ERTS-1 multispectral scanner data employing a Spectral Data Comparator Model 64 Additive-Color Viewer. Flood boundary delineations were based exclusively on spectral data analyzed in the laboratory, although under an operational system spectral analyses would be complemented by ground observations and topographic contour analysis, particularly in forested areas where the multispectral scanner may image reflected radiation from the tree canopy rather than the inundated land surface. The original data used for the analyses in this study were 70 mm MSS negatives. All of the data were reprocessed to balance the density range and minimum density in the balck and white positives with respect to each other. This was done to achieve the greatest enhancement of the flood plains in the additive-color projection described below.

Techniques of data processing, color enhancement of flood features, preparation of two-color temporal composites to display flooded areas regionally, and flood mapping were presented in greater detail at the June 1973 Symposium of the American Water Resources Association on Remote Sensing and Water Resources Management (Deutsch, Ruggles, Guss, and Yost, 1973).

ERTS-1 COVERAGE OF THE 1973 MISSISSIPPI RIVER FLOODS

All of the ERTS data used for this study were obtained by the multispectral scanner (MSS), which images reflected solar radiation from the Earth's surface in four bands of the visible and near-infrared portions of the electromagnetic spectrum, nominally as follows (NASA, 1971):

MSS Band	Wavelength (Micrometers)	Color
4	.5 - .6	Visible, green-yellow-orange
5	.6 - .7	Visible, red
6	.7 - .8	Near-infrared
7	.8 - 1.1	Near-infrared

Figure 2 (left) is a mosaic prepared from ERTS-1, MSS band 7 images showing extent of flooding (dark) over large reaches of the Mississippi River Valley from St. Louis to the Gulf of Mexico. The imagery was obtained by the satellite on March 31 for the western swath including the St. Louis area, and on May 4 and 5 for the eastern swaths. The images were precisely enlarged to a scale of 1:1,000,000. The May 4 and 5 orbital swaths cover about a 2000 kilometer reach of the Mississippi (1200 river miles), from about half way between St. Louis and Cairo, Illinois, to the Gulf of Mexico. The flood is at its peak along the reach between Cairo and Memphis (see Figure 1). Flooding along the lower Ohio River at its confluence with the Wabash River is also clearly shown. The seven May 5 scenes used in the mosaic were collected during an orbital interval of only three minutes. All of the flood data shown in Figure 2 were collected in a total time of about seven minutes.

In order to map the area inundated by any flood, obviously, it is necessary to have data on the area normally covered by water. For this critical analysis, data collected by ERTS-1 over the Mississippi River on October 1 and 2, 1972, were obtained from the Earth Resources Observation Systems (EROS) Data Center at Sioux Falls, South Dakota.

Figure 2 (right) is a black and white mosaic of MSS band 7 images recorded by ERTS-1 sensors on October 1 and 2, 1972, which depicts "normal" conditions. The difference in water-covered or wet surface between October 1972 and the 1973 flood period is obvious. Especially noticeable also is the wet flood plain between St. Louis and Cairo, Illinois, and the lower White River above its confluence with the Arkansas River in the lower left image. For the purposes of mapping the extent of the flood from about St. Louis to Memphis, data from only seven ERTS scenes in October and seven flood images were needed.

Temporal Composite Display of Flooded Areas

The extent of flooding can be clearly displayed by projecting a pre-flood image and one collected during the flood into a single composite image. Band 7 was used because there is little or no reflection of incident radiation from water in this spectral region, and thus the water appears dark in a positive print.

Figure 3 is a mosaic of band 7 temporal composites for the Mississippi River below St. Louis. "Normal" surface-water distribution is shown in black, as determined from the October, 1972 data. Except for cloud shadows, the presence of red depicts water on the surface during the flood period that was not present during "normal" conditions in October. There is a major flooding along the Mississippi above St. Louis and at its confluence with the Missouri River. There is also flooding in the Cairo area, and the flood peak is depicted between Cairo and Memphis. In fact, there is widespread flooding throughout the Mississippi River Valley in the study area. The Ohio River is in flood at its confluence with the Tennessee. The entire valleys of the Kaskaskia River in Illinois, and the White and St. Francis Rivers in Arkansas are very wet and locally in flood. In contrast, the Arkansas River (lower left) is confined to its banks. The change in area of surface storage in several reservoirs is clearly depicted by red extensions beyond their pre-flood shorelines.

Figure 4 shows the Cairo, Illinois, area imaged by MSS band 7 on May 5, 1973, in green, and on October 1, 1972, in red. The temporal composite (bottom), prepared by additive projection of the two band 7 scenes, depicts the flooded area in red, as described below. The composite covers only the area of image overlap between the two dates. This image, therefore, shows excellent differentiation between dry soil, saturated soil, and standing water. In a properly processed positive, standing water is very dark, dry soil is relatively light, and saturated soil is intermediate in density. When a non-flood image is projected as red, in register with a flood image projected as green, the composite color image is composed of the following elements:

1. Where there is surface water present on both images, the composite image receives little or no light and is therefore essentially black. This depicts the area normally covered by the river and other surface-water bodies.

2. Where the ground is not covered with water in both scenes, the composite image received relatively equal amounts of red and green light, and is therefore yellow. This depicts the area unaffected by flood waters.

3. Where there is surface water in the scene projected in green, and dry soil in the scene projected as red, the composite image receives only red light, and is therefore a highly saturated red color. This depicts the area of flood inundation.

4. Where there is water-saturated soil in the scene projected as green, and dry soil in the scene projected as red, the composite image receives red light combined with a lesser amount of green light, and results in a color on a continuum between yellow and red.

It can readily be seen also from Figure 4 that the orbit of the satellite has shifted about 20 miles to west between October and May. Furthermore, the swaths were not framed at the same latitudes for the two dates; hence, the number of temporal composites needed to mosaic the reach of the Mississippi River was doubled.

In general it was considerably more difficult to register scenes covering the same area for different dates to make temporal composites than it was to register the various bands collected simultaneously for the spectral composites. This may be due in part to differences in side edge distortion caused by the orbital shift or by changing width of the rivers. It may also be due in part to slight attitude difference of the satellite. In any event, inasmuch as the flood plains are relatively linear, it was possible to obtain good registration along those flood plains studied at the expense of slight misregistration in distant areas.

Color Enhancements

From inspection of the "standard" false-color composite of bands 4, 5, and 7 images of the flood area produced by the NASA Data Processing Facility (NDPF) (Figure 5) it appeared that the flooding was more extensive on the image than was actually the case. The additive-color viewer was hence used to produce two- and three-color enchancements highlighting conditions on the flood plains.

From among the numerous additive-color combinations examined on the viewer screen the following were deemed to be best for detailed flood-plain analysis or mapping.

Rendition "A" (Figure 5, upper left) - Band 5 is projected as blue; band 6 as green; and band 7, filtered to about 60 percent transmission, as red. This rendition was best suited for interpreting the extent of flooded area in relation to rural land use. Morphologic and geologic features are enhanced, and water detail is well preserved. Areas with standing water appear as blue, and wet or saturated soils as brown.

Rendition "B" (upper right) - Band 6 is projected as red, filtered to about 60 percent transmission and band 7 as green. This pictorial rendition prepared from the two near infrared bands was considered to be the best for differentiating areas of varying degrees of inundation and wetness. This rendition, therefore, was used as the basic source of information from which the flood maps described below were prepared. Standing water appears as red and the wet or saturated flood plain as green.

Rendition "C" (lower right) - Band 4 is projected as blue; band 5 as green; and band 7, filtered to about 40 percent transmission, as red. This pictorial rendition is best suited for interpreting flooded areas in relation to urban patterns. While preserving water detail, it enhances cultural detail. In this rendition, standing water is shown in shades of blue or green, and areas of wet or saturated soil appear as brown.

INTERPRETATION AND FLOOD-MAPPING PROCEDURES

Figure 6 is a flood image-map using the Cairo area temporal composite enlarged to a scale of 1:250,000 as an image base.

The initial area selected for flood inundation map preparation was the ERTS image that covered Cairo, Illinois area at the confluence of the Mississippi and Ohio Rivers. The 1:250,000 scale drainage overlays of NJ16-7 (Paducah quadrangle) and NJ16-10 (Dyersburg quadrangle) were superimposed on a 1:250,000 rendition "B" multispectral enlargement, and the perimeters of the flooded area along the main stems of the Mississippi and Ohio Rivers were drafted (Figure 7).

Area measurements that differentiated normal river stage acreage from flooded inundation acreage were computed by subtraction. The flooded areas were determined with a Dell-Foster 3-axis Digitizer-Quantitizer. This procedure was repeated to complete the analyses of the extent of flooding along the Mississippi River main stem from St. Louis to the confluence with the Arkansas and White River, with results as follows:

Quadrangle	Total Water Area		Normal River Area	
(1x2 degrees)	(km^2)	(mi^2)	(km^2)	(mi^2)
St. Louis	805	311	326	126
Paducah	987	381	344	133
Rolla	75	29	3	1
Dyersburg	1474	569	324	125
Blytheville	723	279	153	59
Memphis	412	159	88	34

	Inundated Land Area	
	(km^2)	(mi^2)
St. Louis	479	185
Paducah	642	248
Rolla	73	28
Dyersburg	1150	444
Blytheville	570	220
Memphis	324	125

Interpretation of Post-Flood Data

Because ERTS-1 coverage is limited to cloud-free coverage once every 18 days, it cannot track the progress of a flood peak. Inspection of data collected by ERTS-1 on May 24, the day the Mississippi River receded to bankfull stage at St. Louis, indicates that changes in surface reflectance characteristics caused by the flooding can be delineated, thus making it possible to map the total area flooded without the necessity of a real-time, continuous system to track and image the peak flood waves. Figure 8 shows an additive-color temporal composite of band 7 images showing the extent of flooding in red on March 31 against normal surface-water distribution on October 2, 1972.

From Figure 1, however, it can be seen that flood stage was at about 38 feet on March 31, but that on April 28 the flood peaked at 43.3 feet, obviously inundating additional areas not flooded on March 31. Figure 8 also shows a temporal composite of the post-flood May 24 data at St. Louis against the October 2, 1972, image. In this composite there are areas shown in red that are not shown on the March 31 - October 2 temporal composite. It is postulated that the later scene indicates changes in surface reflectance characteristics caused by flooding and that the area from which the flood waters receded between April 28 and May 24 is depicted in tones of red.

ERTS MSS Imagery Compared with Aircraft Color Infrared Photography

On April 12, 1973, a NASA U-2 aircraft photographed the Mississippi River in flood below St. Louis. Figure 9 shows U-2 photography at St. Louis, Cairo, and Memphis and the areas covered by five frames in relation to the ERTS-1 multispectral imagery. Inspection - but not analysis - of the U-2 data leads to the following observations:

- The U-2 followed the main valley of the river and missed the effects of flooding of the Mississippi on various tributaries. At

Cairo the camera angle-of-view was not wide enough to cover the entire width of the flood.

- Where turning with the course of the river, the aircraft caused spatial distortions in the film that would require rectification to permit accurate mapping.
- The multispectral mode of the ERTS data permitted automatic, rapid, and accurate delineation of the flooded area, whereas mapping from aircraft photography would require density slicing or use of photo-interpretation techniques.
- ERTS covered the entire region using only a small fraction of the number of frames required by the U-2, which would have been again multiplied were it possible to obtain vertical photography during block coverage.
- The principal advantage of the aircraft data is that it permits mapping by photointerpretation techniques at larger scales, but for limited areas.

POTENTIAL FLOOD APPLICATIONS OF ERTS IMAGERY

The technique described in this report offers a relatively simple and economic procedure that can be used to quickly assess areas that have been inundated during recent flood periods. Rango and Anderson (1973) mapped areas susceptible to flooding along the Mississippi River using pre-flood ERTS imagery at scales as large as 1:100,000. These methods will not replace an engineering type of flood evaluation that requires specific information, i.e., depth of flooding in a basement, the amount or degree of damage resulting from undermined roads, and other structures, or the degree of damage to mechanical equipment and other property in buildings.

The method will provide regional disaster relief agencies with an overview from which they will be able to determine a first cut damage estimate, and thus be able to dispense assistance in the most expeditious manner.

The regional planner will have a tool to enable him to assess the best use of the flood plains. Housing authorities will be able to determine areas subject to flooding; private lending agencies will be able to evaluate the flood potential of a proposed urban development; flood insurance agencies (private and public) will be able to evaluate flooded areas and be able to assist their customers more quickly; engineers will be able to quickly evaluate the effectiveness of flood control works and thereby be provided with a prototype model for a river basin.

The list of possible uses of the ERTS-1 evaluation described herein is only limited by the ingenuity of the user.

CONCLUSIONS

Optically processed ERTS MSS imagery provides hydrologists with a powerful new technique for rapid and inexpensive flood inundation mapping and related studies:

- The areal extent of flood waters over very large reaches of a major river basin can be viewed synoptically.
- Areas in flood can be quantitatively determined by automatic data-processing techniques.
- ERTS imagery can be color enhanced by additive-color techniques to aid in the interpretation of flood conditions and their relation to geologic, physiographic, and urban settings.
- The extent of inundation versus "normal" conditions can be sharply delineated by color combining of pre-flood and flood band 7 images into so called temporal composites.
- The near-infrared bands (6 and 7) on ERTS can be used in combination for interpretation

of flood conditions and delineation of flood-water boundaries.

- Bulk-processed ERTS imagery can be used as the basis for area-of-flood inundation mapping for a region at a scale of at least 1:250,000 and probably as large as 1:100,000.
- Optical data-processing of ERTS MSS imagery provided for an extremely fast and inexpensive means of regionally delineating the Mississippi River floods of 1973, and measuring the areal extent of inundation during the course of the floods.
- Regional flood mapping is far more feasible employing satellite imagery than aircraft photography.
- The effects of flooding on the reflectance characteristics of the surface makes it possible to delineate areas from which flood waters have receded using post-flood data, eliminating the necessity for continuous tracking and imagery of the flood crest and reducing volume of data required.
- Flood-prone area maps generated from ERTS MSS data have potentially important engineering, economic, disaster relief, and planning applications.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Drs. Stanley Freden and Albert Rango of the NASA Goddard Space Flight Center for making the ERTS-1 imagery of the Mississippi flooding available on a priority basis. They are equally indebted to Dr. George Rabchevsky of the Terratek Corporation for his excellent advice and considerable assistance on techniques of color-additive enhancement and false-color reproduction. Data processing and preparation of mosaics were performed by Mr. Philip Guss of Lockwood, Kessler, and Bartlett, Inc. of Syosset, New York, and Dr. Edward Yost of Spectral Data Corporation of Hauppage, New York, under terms of U.S. Geological Survey Contract 14-08-0001-13185. Their scientific and technical expertise provided the foundation for this study.

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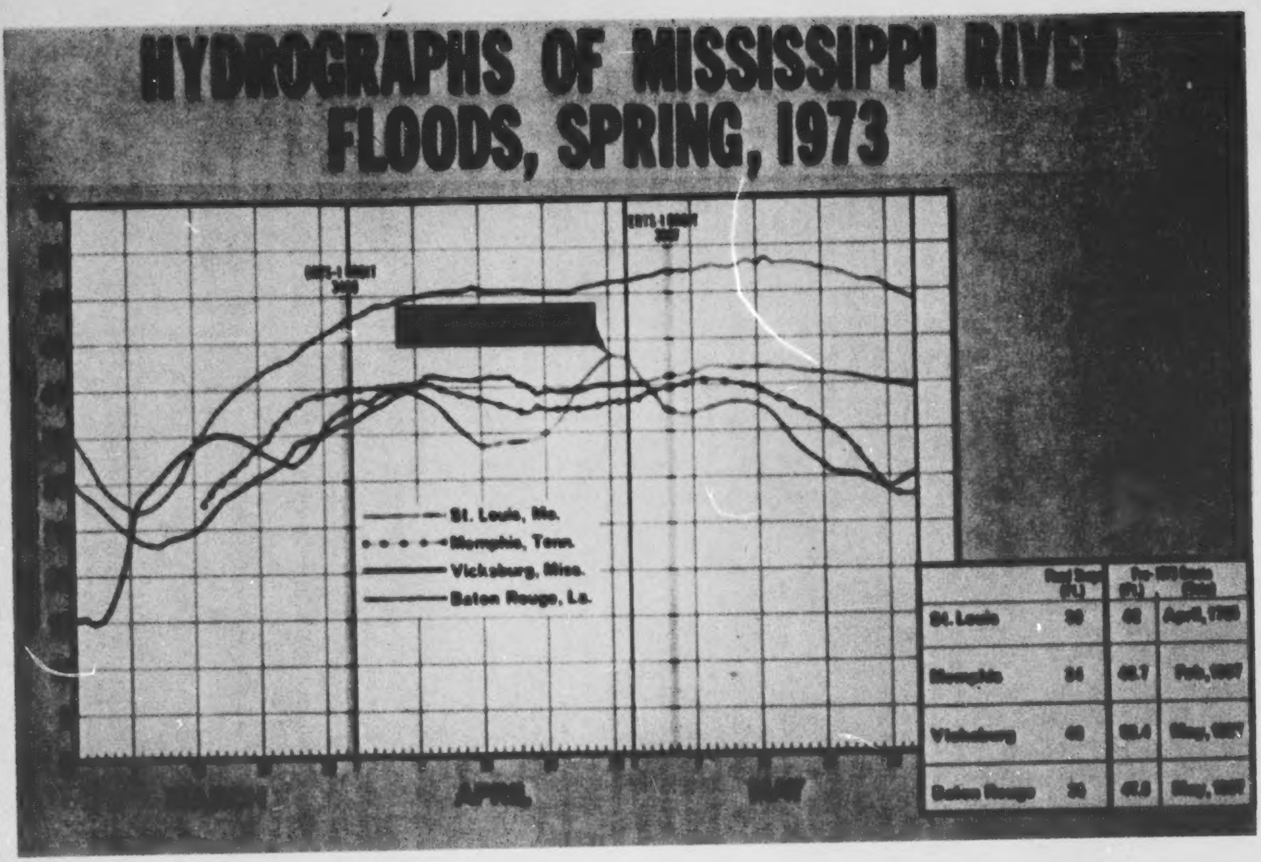

Figure 1. These hydrographs show that the lower Mississippi River was above flood stage for prolonged periods during the spring of 1973.

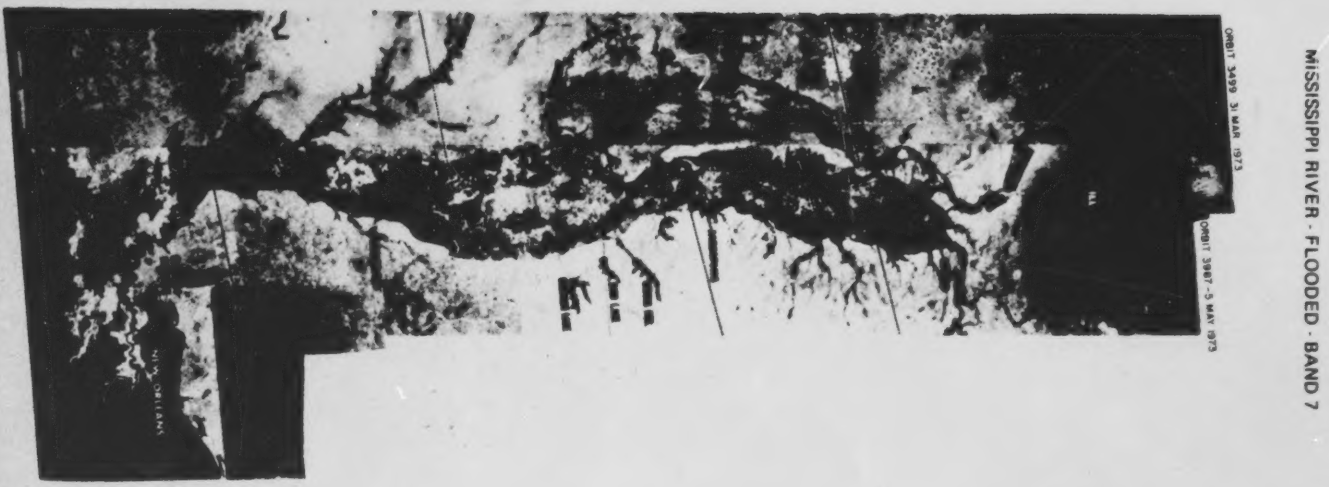
MISSISSIPPI RIVER - FLOODED - BAND 7
ORBIT 3499 31 MAR 1973
ORBIT 3987-5 MAY 1973
NEW ORLEANS

Figure 2 (left). On March 31 and May 4-5, 1973, ERTS-1 imaged the lower Mississippi River Valley in a total time of about seven minutes. This mosaic of band 7 near-infrared images provided the first overall view of flooding for the entire region.

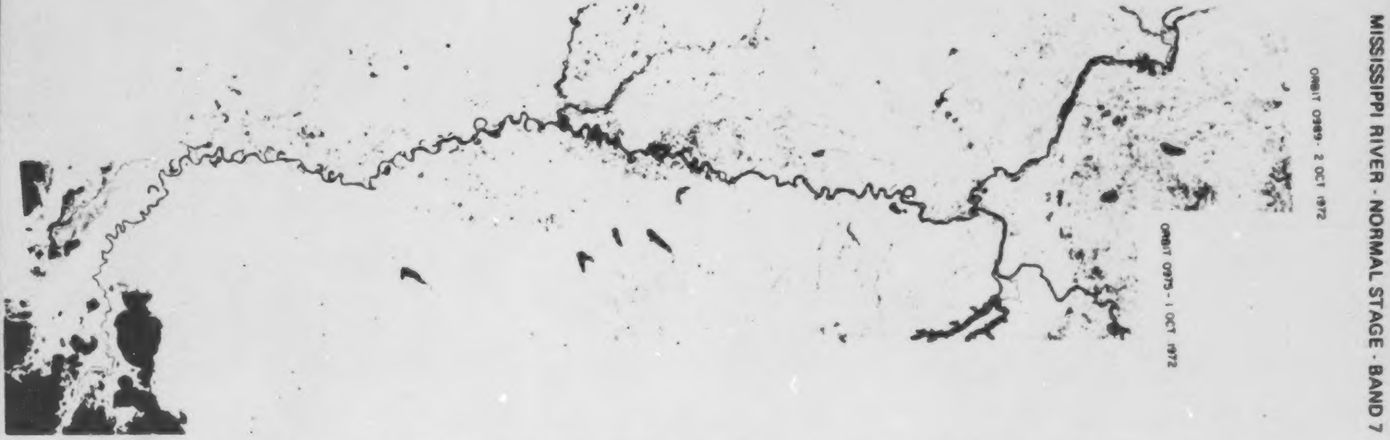
MISSISSIPPI RIVER - NORMAL STAGE - BAND 7
ORBIT 0989-2 OCT 1972
ORBIT 0975-1 OCT 1972

Figure 2 (right). The ERTS flood data were compared with the band 7 near-infrared images used to construct this mosaic depicting "normal" conditions along the Mississippi Valley between St. Louis and the mouth of the Arkansas River on October 1-2, 1972.

Figure 3. This mosaic displays the extent of flooding in red along the Mississippi Valley between St. Louis and the Gulf of Mexico on March 31 and May 5, 1973. "Normal" river conditions and the areal extent of surface water on October 1 and 2, 1973, appear as black. The mosaic was prepared by color combining the pre-flood data with flood data as illustrated by Figure 4.

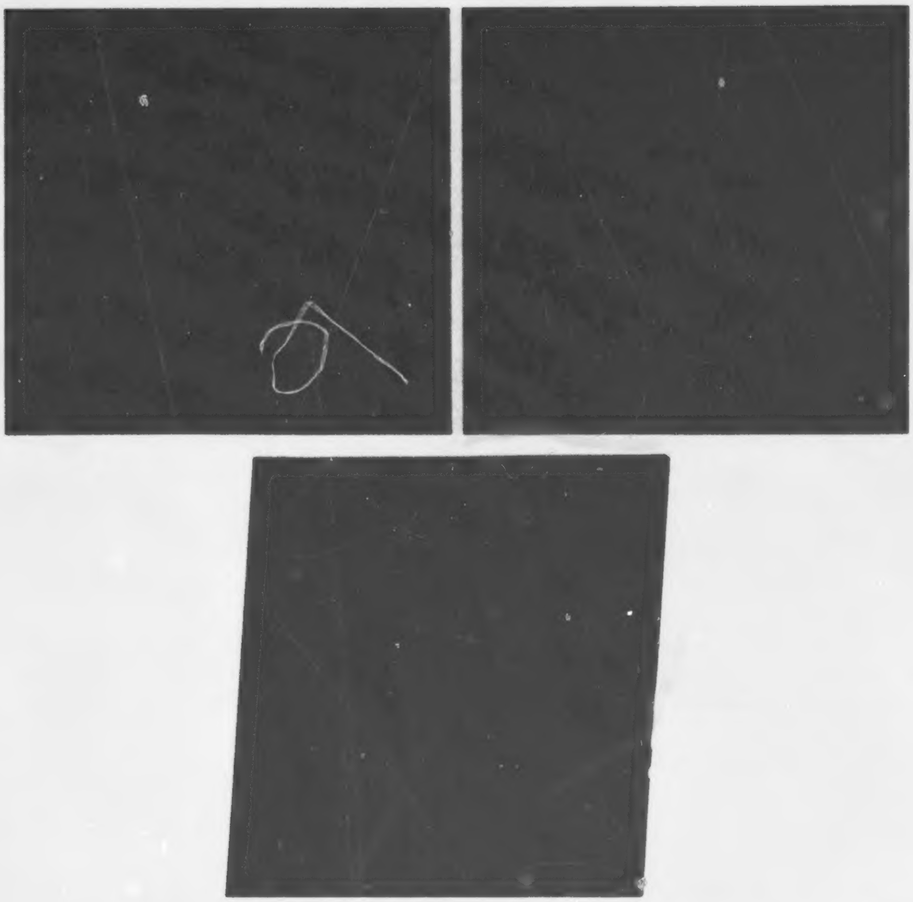

Figure 4. Band 7 images covering the flooded areas (green) were combined with images of the same area collected under "normal" conditions (red) to prepare temporal composites (bottom) such as the one shown here at the confluence of the Mississippi and Ohio Rivers. The extent of flooding is depicted in red; "normal" conditions in black. Yellow depicts areas not affected by flooding.

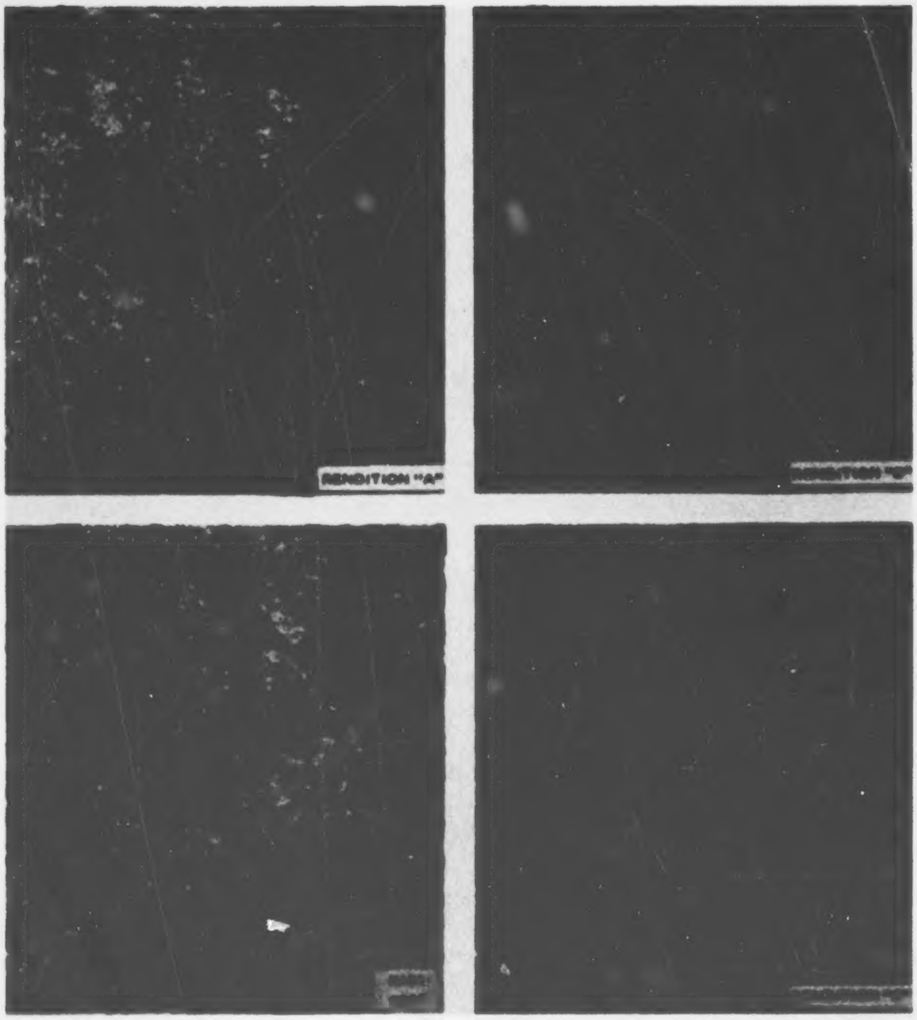

Figure 5. Three specially filtered additive-color enhancements, along with the "standard" NASA Data Processing Facility color composite, were prepared from ERTS-1 multispectral scanner images to study detailed flood-plain conditions north of the confluence of the Mississippi, Arkansas, and White Rivers on March 31, 1973.

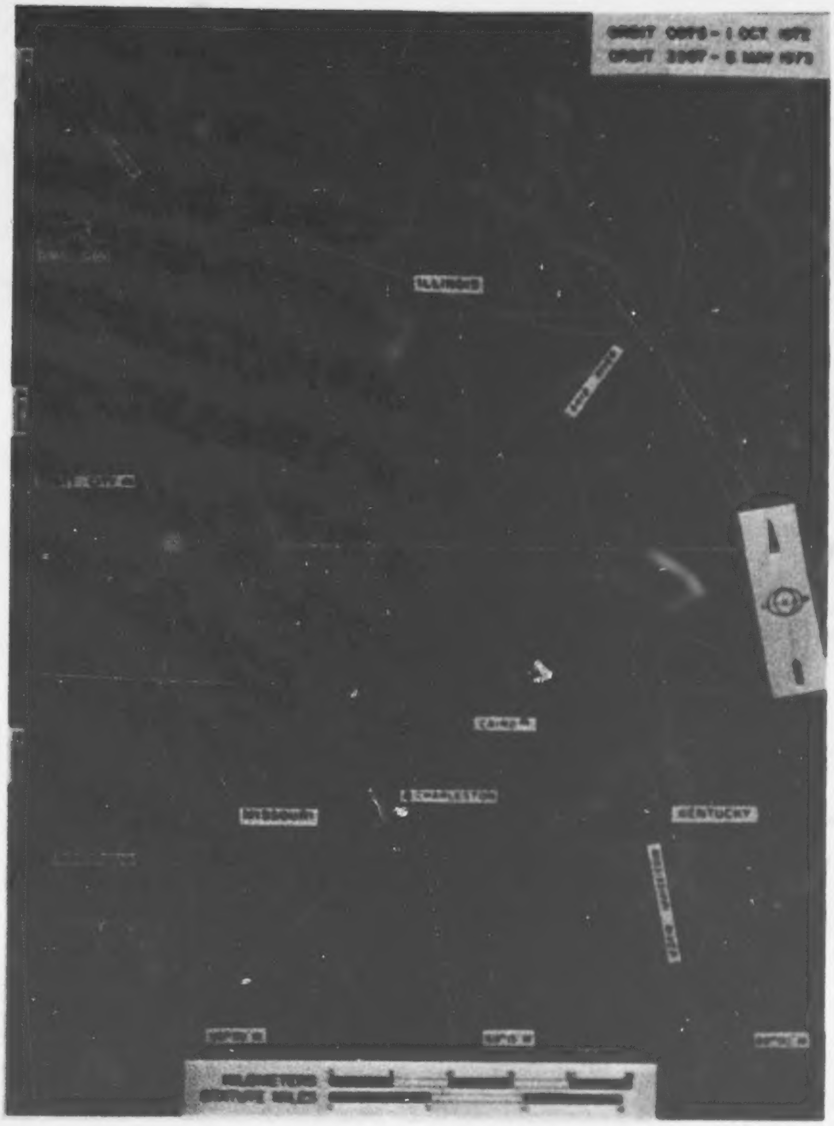
MISSOURI
CHARLESTON
KENTUCKY

Figure 6. Detailed distribution of flooding in the Cairo, Illinois, area is shown in red on this image map prepared from an enlargement to a scale of 1:250,000 of the temporal composite shown on Figure 4.

270

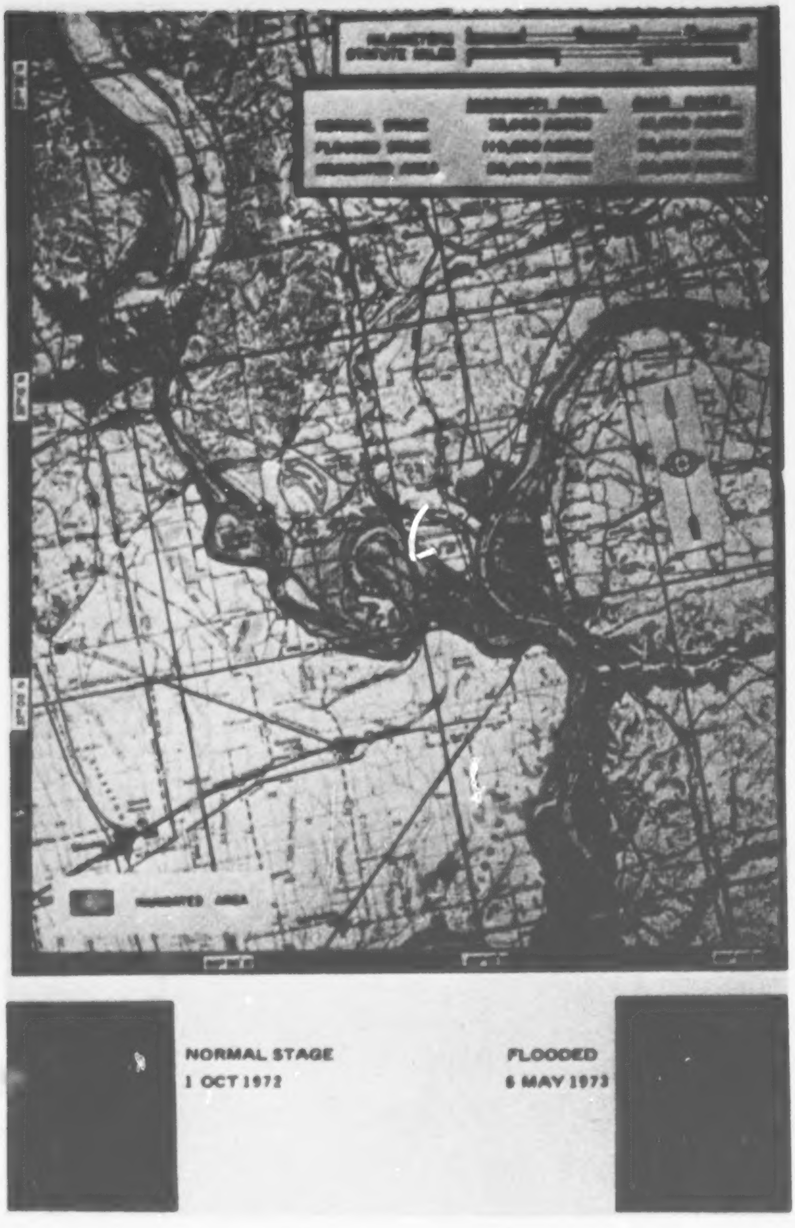
NORMAL STAGE
1 OCT 1972
FLOODED
5 MAY 1973

Figure 7. This map showing the extent of flooding along the main stems of the Mississippi and Ohio Rivers near Cairo, Illinois, was based exclusively on band 6 and 7 near-infrared images collected by ERTS-1 on October 1, 1972, and May 5, 1973.

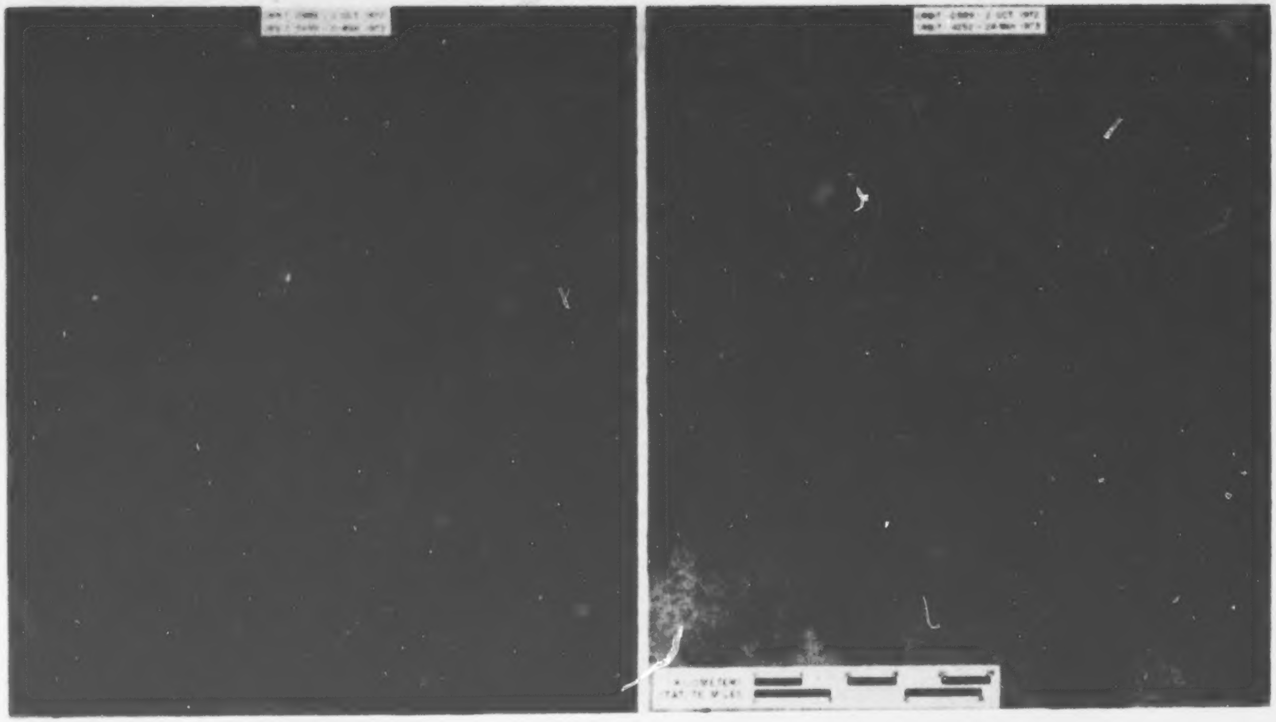

Figure 8. These temporal composites depict flood conditions against "normal" conditions in the St. Louis area where the Illinois and Missouri Rivers join the Mississippi River. On the left, the extent of flooding on March 31, 1973 is shown in red; on the right, red indicates the area from which flood waters receded between April 28 and May 24. 1973.

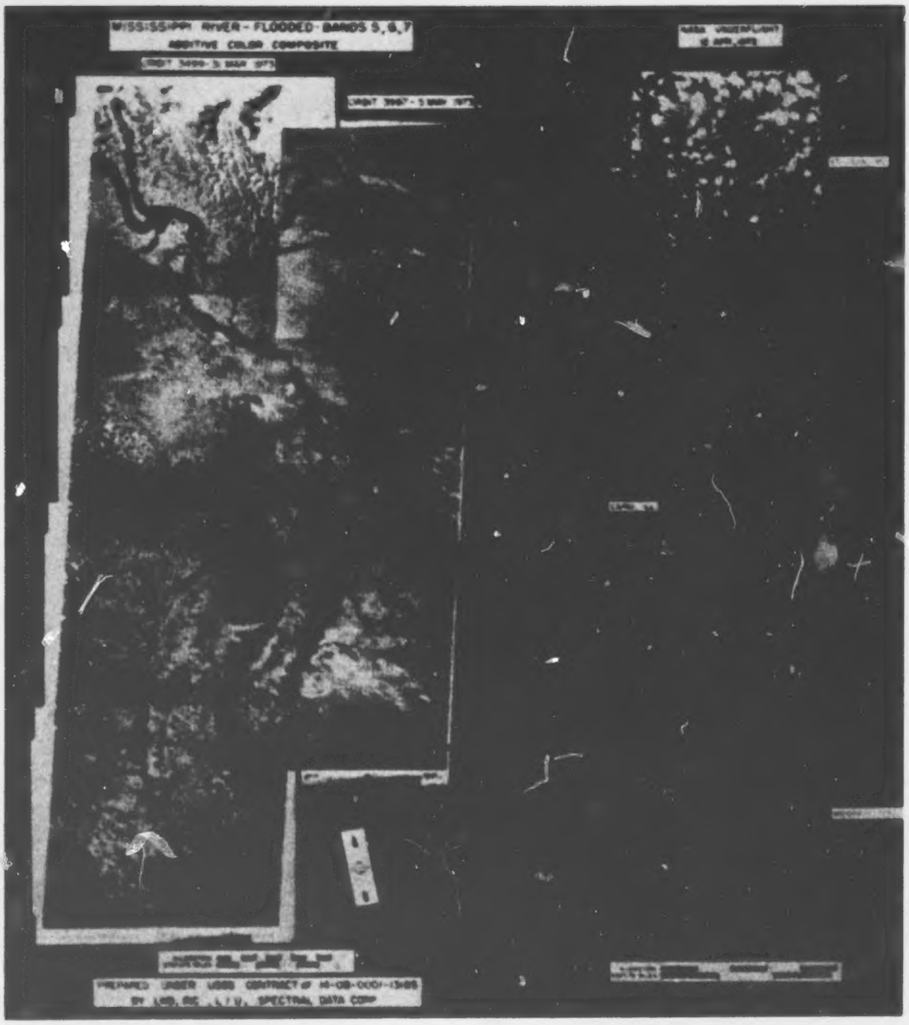
MISSISSIPPI RIVER - FLOODED - BANDS 5, 6, 7
ADDITIVE COLOR COMPOSITE
PREPARED UNDER USGS CONTRACT
SPECTRAL DATA CORP

Figure 9. ERTS MSS imagery provides superior synoptic and regional coverage over the Mississippi River between St. Louis and Memphis, but high-altitude aircraft color infrared photography shows greater detail at St. Louis, Cairo, and Memphis.

MISSISSIPPI RIVER VALLEY

Vocabulary - Define the following terms in detail.

- Multispectral Scanner System
- Hydrographs
- Flood Inundation
- Micrometers
- EROS
- Additive color
- False color

Questions - Answer the following inquiries in detail.

1. How was ERTS used to map flooding?
2. What are implications of the all time flood crest in St. Louis?
3. What was the advantage of using ERTS data over conventional methods of flood inundation mapping?
4. How high above flood stage did the Mississippi River reach historically at St. Louis, Memphis, Vicksburg, and Baton Rouge?
5. What were the objectives of the ERTS-1 MSS scanner in relation to the flood?
6. Explain the use of color enhancements.
7. How was the interpretation made of the flooded area utilizing what flood mapping procedures?
8. What was the total flood area in km^2 and in mi^2 of St. Louis, Paducah, Rolla, Dyersburg, Blytheville, and Memphis?
9. What did the inspection of U-2 data find?
10. What potential applications to a flooded area are available to a user through ERTS imagery?
11. What conclusions were reached?

Discussion Topics

1. What economic problems occurred after the Mississippi flooding?
2. Is the Mississippi Valley in an earthquake zone? Why or why not? Discuss in detail.

APPLICATIONS OF ERTS-1 IMAGERY TO TERRISTRIAL AND MARINE ENVIRONMENTAL ANALYSES IN ALASKA

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ABSTRACT

ERTS-1 imagery provides a means of distinguishing and monitoring ESTUARINE surface water circulation patterns and changes in the relative sediment load of discharging rivers on a regional basis. This information is being used to produce a data base useful in regional planning and in the development of management programs as required by the Coastal Zone Management Act of 1972. It also will aid local fishing industries by augmenting currently available HYDROLOGIC and navigation charts.

The interpretation of geologic and vegetation features resulted in preparation of improved surficial geology, vegetation and permafrost terrain maps at a scale of 1:1 million utilizing ERTS-1 Band 7 imagery. This information will be further utilized in a route and site selection study for the Nome to Kobuk Road in central Alaska.

Large river icings along the proposed Alaska pipeline route have been monitored. Sea ice deformation and drift northeast of Point Barrow, Alaska has been measured during a four day period in March and shorefast ice accumulation and ablation along the west coast of Alaska is being mapped for the spring and early summer seasons. These data will be used for route and site selection, regional environmental analysis, identification and inventory of natural resources, land use planning, and in land use regulation and management.

INTRODUCTION

Two of the greatest problems in arctic and subarctic environmental research have been the absence of long-term observational data and sparse geographical coverage. Studies of synoptic environmental events over regional-sized areas have been either impossible or prohibitively expensive. Problems of resource utilization have recently been dramatized in Alaska, where a severe lack of basic environmental data and understanding has collided with rapidly mounting pressures for extensive development of extractive industries, transportation systems, and population centers. The existing information on river, lake, and coastal hydrology, and on the distribution, properties and behavior of permafrost terrain is insufficient for an understanding of the various environments and their interrelationships. The history of construction and technological development in these areas dramatically illustrates the difficulties caused by environmental extremes and the possibility of serious unforeseen consequences of disturbing established environmental equilibria.

Two examples illustrate the point. The proposal to construct a trans-Alaska pipeline several years ago created an urgent need for general and specific information on the environment across the entire state. Voluminous data were obtained, but at a high cost, and with a great effort by many individuals. Some of the data, especially that pertaining to route selection and regional patterns of soils, vegetation, and the distribution of permafrost could have been acquired at a considerable savings of money and manpower had ERTS imagery been available.

Now that the decision to begin construction on the pipeline has been made, this need has again become critical. The top three research topics identified recently by the Alaska Oil and Gas Association are: 1) ice forces, features and movements, 2) permafrost distribution and behavior, and 3) landfast ice surveys. The need to develop remote sensing methods to rapidly map the distribution and properties of sea ice, permafrost and shorefast ice in Alaska was given high priority at the Second International Conference on permafrost held this summer in Yakutsk, Siberia and is being highlighted by a National Science Foundation ad hoc committee on priorities in permafrost research. Accurate, up-to-date maps of permafrost and shore fast ice are urgently needed in final route selections, selection of pumping stations and off-shore loading facility sites, and the planning and implementation phases of pipeline and facilities construction.

The second example of a situation where the availability of ERTS imagery could have resulted in cost savings and better utilization of resources is the harbor construction at Dillingham. Following construction, it was discovered that siltation rates were so high that they threatened to render the new facility useless within a short time. Continuous dredging is required to maintain the harbor throughout the ice-free season. A more favorable site could have been selected and a serious and expensive problem avoided had better information on the regional and local circulation patterns been available. Similar projects in other localities are in the planning stages. Based on the results reported here, it is clear that information to help avoid such difficulties is now available.

The objectives of this investigation are:

1. To develop application of ERTS-1 imagery in a synoptic study of surface circulation patterns, tidal flat configuration, SUSPENDED SEDIMENT distribution and water mass boundaries in Cook Inlet.

2. To utilize ERTS-1 imagery in the analysis

of the relationships between the distribution of permafrost terrain on a regional scale and geologic, vegetative and other environmental factors.

3. To identify and interpret the physical and cultural features representative of the major physiographic provinces of Alaska for the purpose of demonstrating the effectiveness of ERTS-1 imagery in cold regions research and engineering.

As indicated above, coastal processes were analyzed in Cook Inlet (area 4, Fig. 1). Surface circulation patterns, tidal flat configuration, suspended sediment distribution and water mass boundaries were mapped from MSS bands 4 and 5 imagery. A 10-scene photo mosaic of a 153,400-km^2 area in north-central Alaska (area 3, Fig. 1) was constructed for a regional environmental analysis from MSS band 5 imagery. Seven surficial geology, eight vegetative cover and four permafrost terrain units were defined and delineated on this photo mosaic. Permafrost units were differentiated and delineated from tonal and textural patterns related to surficial geology and vegetation. The distribution of shore fast ice along the Alaskan coast was examined from Point Barrow to Cape Krusenstern (area 2, Fig. 1) using imagery acquired during the March 1973 ERTS passes and an analysis was made of the deformation of the Arctic pack ice north of the Alaskan coast from Point Barrow to Harrison Bay (area 1, Fig. 1).

COASTAL PROCESSES IN COOK INLET

Cook Inlet is a large tidal estuary in south-central Alaska. It is oriented in a northeast-southwest direction and is approximately 330 km long and increases in width from 37 km in the north to 83 km in the south. The inlet is bordered by extensive tidal marshes, lowlands with many lakes, and mountains. Anchorage, the state's most populated city, is located at the head of Cook Inlet and is the center of transportation, commerce, recreation and industry. The use of Cook Inlet as a water route to this growing urban area will increase as the development of the regional resources continues. The estimated petroleum and gas reserves of the Cook Inlet area are 7.9 billion bbl and 14.6 trillion cubic feet, respectively (Crick, 1971). Coal deposits in the Beluga River region are estimated at more than 2.3 billion tons (equivalent to approximately 7 billion barrels of oil) (Evans et al, 1972). In view of present acute energy requirements rapid development of this potential is inevitable.

Trading Bay, on the western side of the inlet has 14 oil and gas producing platforms around Middle Ground Shoal. It is the major site of petroleum production in the Cook Inlet area. An oil refinery and a tanker terminal are located at Nikiski 15 miles across the Inlet and a tanker terminal is also located at the mouth of the Drift River approximately 30 miles southwest of Trading Bay. Numerous submarine pipelines cross the inlet and several crude oil gathering facilities are located along the coast. Additional offshore platforms, coastal facilities and tanker terminals will be constructed as petroleum production increases and as the southern portion of the inlet is developed. Increased utilization of the coastline will follow as facilities are constructed in support of the petroleum industry.

The environmental effects of the regional development must be considered in formulating future plans for the region. The present amounts and types of pollution in the inlet will increase so the capability of the inlet to disperse the additional pollutants must be determined. Suspended sediment is currently the dominant pollutant in the inlet. It is estimated that in newly developed areas as much as 20,000-30,000 times more sediment is produced than in natural undisturbed areas (Environmental Currents, 1972). The following rivers contribute the greatest amount of sediment to the inlet - Knik, Matanuska, Susitna, Beluga, MacArthur, Drift and Tuxedni. The watersheds of these rivers are now the areas of greatest utilization and future use will increase their sediment production.

Other sources of inlet pollution are the coastal towns. With completion of the Asplund Water Pollution Control Facility the sewage from the Greater Anchorage Area Borough is treated prior to being discharged into the inlet near Point Woronof. This project is the single most important environmental protection measure so far undertaken in the Anchorage area (Alaska Construction and Oil, 1973). The remaining cities and villages bordering the inlet discharge untreated sewage directly into the inlet.

Petroleum pollution in the inlet originates from numerous sources: 14 producing offshore platforms, the Drift River, Arness or Nikiski tanker terminals, submarine and coastal pipelines, the gathering and handling facilities along the coast and wastewater effluent from the Standard Oil and Tesboro refineries. Approximately 9500-17500 bbl/yr or 0.3% (Kinney, et al., 1970a) of the total crude produced is accidentally spilled but, to date, the spills have not been obviously detrimental to coastal areas. From January through April 1972, 5 spills occurred in the inlet as a result of accidental disconnects at tanker terminals with evidences of the spills disappearing in 3-4 days (Kinney, et al, 1970a). Because of the high surface turbulence and mixing, oil spills rarely reach shore; they simply evaporate and disperse as they move up and down the inlet with the high tidal fluctuations.

Petro-chemicals from the Phillips liquified natural gas plant and the Collier Chemicals ammonia plant at Nikiski are introduced in the inlet. The effluent outfalls from these plants are located in a region of high turbulence. Dilution of the wastes is rapid and concentrations remain below harmful levels even during the low runoff winter months (Rosenberg, et al., 1967).

The movement and strength of ice in Cook Inlet is another particularly important aspect of the inlet environment to be considered when offshore construction is planned. The inlet ice is seasonal and remains for approximately 4 months of the year. It is fine- to medium-grained (1mm-4mm) with a salinity of .4-.6‰ and a ring tensile strength of 10-20 kg/cm^2. The inlet ice exists as large floes which are commonly greater than 320 meters across with individual blocks generally less than 1 meter thick. Pressure ridges up to 6 meters in depth occasionally form (Blenkarn, 1970). The large floes move up and down the inlet with the 6-8 knot currents which are produced by 9-meter semidiurnal tides. The regional circulation patterns that move the ice floes within Cook Inlet are controlled primarily by the interaction between the semidiurnal tides and the Coriolis force.

Using suspended sediment in the inflowing fresh water as a tracer, the current patterns have been distinguished in MSS bands 4 and 5 imagery. The distinction between the saline, oceanic water in the southeastern portion of the inlet and the fresher sediment-laden, inlet water in the northern and southwestern portions has been used to detect changes in the sediment distribution and movement of the water masses.

Figure 2a shows differences in the main boundary between the oceanic and fresh water in the southern inlet on two successive days. The boundaries separate the two major water types during low tide at Anchorage and high tide at Seldovia. The irregularity of the western portion of these lines may be due to the upwelling of cold, saline oceanic water that occurs in the western portion of the inlet (Kinney et al. 1970b; Evans et al. 1972). The northern portion of the 4 November boundary is also quite irregular, possibly due to a similar cause. Some estuaries are characterized by a salt water wedge that moves headward along the bottom while the fresh water outflow moves over the wedge and out the estuary (Bowden 1967). In Cook Inlet a subsurface tongue of oceanic water progresses headward and moves up the shoaling bottom of the inlet to the latitude of Tuxedni Bay where it rises to the surface south of Kalgin Island during flood tide (Kinney et al. 1970b). The upwelling waters appear as a large area of clear water surrounded by sediment-laden water. This process produces a zone of high nutrient concentration in the PHOTIC zone at this location. This may be significant to the fishing industry since certain species of fish may tend to concentrate in this high nutrient area. Changes in the boundary over an 18-day cycle are shown in Figure 2b. These boundaries are generally comparable to those in Figure 2a. Although changes in the sediment distribution and surface circulation produce some obvious alterations in the regional distribution of water types, the overall relationships appear to persist with time.

REGIONAL ENVIRONMENTAL ANALYSIS

The first usable ERTS-1 images for our investigation were obtained during orbit 30 on 25 July 1972. Since then more than 3,000 individual scenes have been reviewed. Those images that are relatively cloud-free and taken at acceptable sun elevations have been used to construct a number of photo mosaics of areas chosen for detailed analysis.

The surficial geology was mapped on the 1:1 million scale photo mosaic (Fig. 3) with the aid of stereo pairs and other available GROUND TRUTH. Seven recognizable units are defined (Fig. 4). Bedrock (b) consists of IN-SITU bedrock and very coarse, rubbly bedrock colluvium primarily confined to steep slopes and mountain crestlines. BEDROCK-COLLUVIUM (bc) is composed of coarse- to fine-grained deposits occurring on moderate to steep slopes in mountainous terrain and rolling uplands which have minor scattered bedrock exposures restricted to the uppermost slopes and crestlines. ALLUVIAL-GLACIOFLUVIAL deposits (Qag) are fine- to coarse-grained sediments derived from reworked glacial and alluvial deposits, morainal deposits, till, and outwash gravels and sands. These deposits occur in part on modified morainal topography and large alluvial terraces. FLUVIAL-LACUSTRINE deposits (Qfl) consist of fine-grained sands and silts associated with abandoned floodplains and low-lying terraces. They may include windblown sand and silts. UNDIFFERENTIATED ALLUVIAL deposits (Qal) are fine- and medium-grained alluvial fan, terrace, stream and eolian deposits. FLUVIAL deposits (Qfp) are fine- and medium-grained silts and sands, generally well rounded, associated with modern floodplains and low-lying terraces. EOLIAN deposits (Qe) are fine-grained windblown sediments, deposited on gently to moderately sloping hills and low-lying flatlands and include areas of actively drifting dunes.

The units defined for mapping the surficial geology and the surficial geology map made from the ERTS-1 imagery at 1:1 million scale were subsequently compared to USGS Miscellaneous Geologic Investigations Maps at a scale of 1:250,000 (Cass 1959, Patton 1966, Patton and Miller 1966, Webber and Péwé 1970) and the 1:1.5 million scale Surficial Geology of Alaska map (Karlstrom et al 1964). From these comparison, it was established that the surficial geology map made from ERTS-1 imagery correlated favorably with the published 1:250,000 maps and is superior to the 1:1.5 million map.

VEGETATION

Vegetation is one of the most important indicators of the permafrost characteristics of an area, but the relationship is complex (Hopkins et

TABLE 1. RELATIONSHIP BETWEEN VEGETATION ASSOCIATION AND DEPTH OF THAW (HOPKINS et al. 1955)

Vegetation	Depth of thaw (m)
Tall willows on floodplain	2.4
Mixed alder, willow, white birch	1.2
Mixed stands of white spruce and white birch	0.6 - 0.9
Black spruce in tundra or muskeg	0.3

al. 1955). Vegetation primarily influences permafrost terrain by affecting the atmosphere-lithosphere, thermal exchange and the moisture regime in the soil (Trytikov 1959). Vegetation retards soil warming in the summer and cooling in the winter, but the depth of the active layer also depends on other variables, such as the depth of winter snow and drainage conditions during summer. Vegetation type and density in a permafrost region are most directly related to soil type and drainage conditions. The value of a map of vegetation patterns lies in its relationship to the depth of seasonal thaw. The vegetation association - depth of thaw relationship where permafrost is present in the discontinuous permafrost zone is shown in Table 1.

Vegetation differences are apparent on the MSS imagery primarily through tonal rather than textural patterns. The tonal differences are related to vegetation density and species composition. Eight density levels have been identified and mapped (Fig. 5). Ground truth was obtained from existing mapping by Spetzman (1963) and from oblique photography from a small aircraft by the investigators. Tall to moderately tall, closely spaced spruce-hardwood forest (Fc) consist of white and black spruce with paper birch, aspen, and balsam poplar on moderately to well-drained sites such as active floodplains, mountain slopes (especially southern slopes) and highland areas. The second plant association (Fou) has basically the same species as the closely spaced spruce-hardwood forest (Fc) except the vegetative cover appears less dense. Also the Fou unit has an ecological setting similar to Fc but it extends to somewhat less favorable habitats. Open black spruce forest (Fo) has stunted, open tree growth which includes tamarack, white birch and white spruce in addition to the dominant black spruce. Thick moss, grasses and heath comprise the ground cover. Open black and white spruce forest (Fod) is confined to several isolated areas where the forest has overgrown and stablized sand dunes. This forest tends to be open, but is better drained and not as stunted as within the Fo class. Moist tundra (Tm) occupies vast areas of poorly to moderately drained topography. It contains some stunted black spruce within the southern two thirds of the study area. Cottongrass tussocks are the dominant vegetation form, with sedges and dwarf shrubs where tussocks are absent. Wet tundra (Tw) consists of sedge and cottongrass with few woody plants. This association is distinguished from Tm by the presence of many thaw lakes and wet areas. Shrub thickets (St) are dense thickets of alders, willows, blueberries and other woody, berry shrubs found in coastal areas and floodplains north of the timberline. Extensive areas of this association in the northern foothills are indicated on existing vegetation maps. However, a distinctive pattern is not visible in the ERTS mosaic because of an extensive snow cover existing at the time this imagery was acquired. Alpine tundra (Ta) is primarily barren, but locally dominated by low heath shrubs, prostrate willows and dwarf herbs. This association is generally found at elevations over 600 m.

PERMAFROST

Permafrost is formally defined solely on a temperature basis. It is rock or soil material, with or without moisture or organic matter, that has remained continuously below 0°C for two or more years (Ferrians 1969). It occurs where the depth of winter freeze exceeds the depth of summer thaw, and is classified into two broad categories: continuous and discontinuous. In the continuous permafrost zone (Fig. 6), permafrost lies beneath all land areas, but it is absent directly beneath large water bodies, which provide a sufficient heat reservoir to keep underlying materials unfrozen (Williams 1970). The thickness of permafrost in this zone ranges from several hundred feet in the south to an extreme of more than 600 m. in northern Alaska. The boundary that separates these two zones is theoretically distinct but imperfectly located. Climatically, it approximates the mean southern position of arctic air in summer (Bryson 1966); it is close to the southern limit of the tundra (MacKay 1972) and is the effective limit of active ice-wedges and pingos (Péwé 1966). The discontinuous permafrost zone is a complex mosaic of frozen and unfrozen ground with permafrost thickness decreasing in a southerly direction.

Permafrost is a major environmental factor in Alaska and other high latitude regions. The existence of permafrost is the result of complex interactions among environmental factors such as local microclimate, plant cover, the insulating qualities of the organic and vegetative layers, texture and moisture content of the soil, surficial geology and topographic position. Figures 7 and 8 illustrate typical permafrost settings and the nomenclature in current use.

In central Alaska the distribution of permafrost is discontinuous because the present climate in this area is near the threshold values for the continued existence of permafrost. Only in well-protected locations such as north facing slopes, shaded valley bottoms, or high elevations within the region does permafrost exist. Minor changes in the thermal regime, whether natural or man-induced, can produce major alterations in permafrost landscapes.

Existing maps of permafrost distribution are general, primarily because of the lack of extensive, detailed data (Ferrians 1969). The delineation of the boundaries supporting permafrost mapping units by oonventional aerial photography has been found to be difficult, requiring extensive ground studies to confirm. There is no precedent study in which permafrost terrain has been classified utilizing imagery of the scale and resolution available with ERTS. Consequently, it could not be known in advance the extent to which the more subtle tonal and textural changes on the MSS images might show large scale patterns not discernible in aerial imagery and useful in differentiating among the various types of permafrost terrain. The ERTS-1 MSS imagery exceeded expectation in this respect. Large scale patterns easily identifiable on the imagery include thermokarst topography, icings (naleds, aufeis), beaded drainage, and permanent ice fields. Smaller features, such as pingos/palsas, ice wedge polygons, solifluction lobes, nivation terraces, and stone polygons and stripes could not be identified at the resolution afforded by the multispectral scanner system.

As shown in Figure 9, four permafrost terrains have been mapped based on the interpretation of surficial geology and the probable depth of thaw inferred from the vegetative association.

Other mapping criteria, temperature and permafrost properties, are not observable on the ERTS imagery and were not used in the permafrost terrain mapping. The bedrock (m) terrain is characterized by a thaw depth of 0.3 - 1.0 m except on south-facing slopes where thaw depths may exceed 2 m and a few scattered taliks. Soils are coarse-textured and shallow. Alpine vegetation occurs on the highest, steepest area with black spruce and paper birch on the north-facing slopes. The principal trees on south-facing slopes are white spruce, paper birch, quaking aspen and alder. The alluvium-colluvium (u) permafrost terrain has a thaw depth of <0.5 m in areas of poor drainage and 0.5 - 2.0 m and numerous taliks on moderately to well-drained slopes. Fine-grained, shallow soils occur on steep slopes and medium-to fine-grained, deep soil on gentle slopes. Alpine vegetation occurs on summit positions and black spruce and paper birch on north-facing slopes. White spruce, quaking aspen and alders are found on the south-facing slopes. Moist tundra occurs on poorly drained footslope positions. The active floodplain (l_1) terrain is characterized by numerous taliks, a thaw depth of more than 2.0 m, and fine-grained, deep soils. Balsam poplar, paper birch and white and black spruce dominate. The fourth permafrost terrain unit, abandoned floodplain and terrace (l_2), is characterized also by numerous taliks but contains many small thaw lakes. Soils are fine-grained and shallow with permafrost occurring at depths usually less than 0.5 m. Vegetation includes moss, lichens, low lying shrubs and black spruce. Using these criteria, a permafrost terrain distribution map was prepared with considerably greater detail than that previously available. It is quite feasible by extending these techniques, to rapidly produce improved more detailed permafrost maps than those presently in existence.

ICINGS

Icings (naleds, aufeis) are masses of surface ice characteristic of permafrost terrain formed during the winter by continual or successive freezing of ground water that finds its way to the surface in rivers or springs (Muller, 1947). Repetitive overflows become layers of stratified ice, often creating very large masses. During the late stages of formation the ice mass often extends considerably beyond the boundaries of the normal stream channel. In such cases, icings can become hazardous. Icings may spread over or encroach upon roads, for example. Also ice blocked drainageways may lead to washout of embankments during spring than (Carey 1973). Icings tend to occur at the same locations from year to year, although the amount of icing development varies considerably. The ability to survey and monitor the occurrence of icings by satellite imagery in uninhabited areas will provide valuable information for final selection of the Alaska pipeline route.

The principal environmental factors influencing icing development include precipitation prior to freeze up which influences streamflow during the winter, the depth of snow during the winter which influences the depth of frost penetration in the ground, and temperature regimes during late winter and early spring when icing formation usually occurs. The effectiveness of ERTS imagery in defining seasonal changes in the ice cover of water bodies was quickly demonstrated. Large river icings were not observed in the interior of Alaska during the 1972-1973 season, but on the North Slope of the Brooks Range, many icings were located, identified and monitored through two or more satellite passes. During the formation in late winter and spring, water overflowing ice surfaces appears as a very dark tone against the white snow background on MSS band 7 imagery. Later, after the snow cover has disappeared, icings appear white in all bands and contrast sharply with the surrounding landscape. A number of icings were observed along the proposed Alaskan pipeline route from Prudhoe Bay to the Brooks Range (Fig. 10). Along the Echooka River, a tributary of the Sagavanirktok River, an icing some 16 feet in thickness is visible on the ERTS MSS band 7 image (ID 1251-21123). Other icings are identified on the Kaparuk (1), Toolik (2), Sagavanirktok (3), Ivishak (4), Echooka (5) and Shaviovik (6) Rivers (Fig. 10). Many of these are seen to persist throughout the year. A knowledge of their location and seasonal dynamics is useful in planning routes and scheduling construction activity on the Alaskan North Slope and the Arctic Coastal Plain.

SEA ICE/SHORE FAST ICE

Development of the North Slope oil reserves together with offshore docking facilities and northern sea transportation routes has generated a need for a rapid method of assessing sea ice deformation and drift. Measurements of this type are needed in the formulation of realistic prediction models. Three particular types of data are especially in demand: 1) data on ice deformation across the shear zone region where the moving pack impacts and grinds against stationary shore fast ice, 2) the formation, distribution and persistence of the shore-fast ice, and 3) sequential deformation measurements on a variety of SPATIAL scales at representative locations to determine the regional characteristics of the ice velocity field.

Prior to ERTS-1, satellite sensors did not have sufficiently high resolution for measurements of ice deformation, thus investigations utilizing meteorological satellite data have been primarily qualitative. Even with this limitation, however, it has been possible to detect gross ice boundaries, calculate ALBEDO maps on synoptic scale, and improve our knowledge of the heat balance of the Arctic Ocean (Wendler 1973).

ERTS-1 provides, for the first time, regional scale multispectral imagery with sufficiently high resolution to perform detailed ice studies. Preliminary analysis has shown that the various ice types and features, fast ice, pack ice of various concentrations, brash ice, rotten ice, leads, fractures, puddled areas, and flooded ice, can be identified (Barnes et al. 1973) and first year floes may be differentiated from multiyear floes (Campbell et al. 1973).

In an analysis using high resolution multispectral ERTS-1 imagery of a portion of the Beaufort Sea, it has been possible to determine sequential positions on the ice pack. The data collected for analysis represent a four-day deformation sequence across the shear zone northeast of Point Barrow, Alaska (Fig. 11a and b), and the results have relevance to the boundary conditions used for drift calculations. Analysis suggests that the pack is behaving as a relatively cohesive mass (i.e. highly viscous) with slippage over a narrow region (~50 km) at the boundaries. This indicates that the assumption of no slip at the boundary coupled with a single VISCOSITY model is probably not tenable for the arctic ice pack (Crowder, et al. 1973).

This study, recognizing certain limitations, illustrates how satellite imagery may be used to assess regional deformation and drift of arctic pack ice. The most serious limitation is the difficulty of obtaining sequential, cloud-free imagery coincident with the occurrence of significant deformation.

The distribution of shorefast ice along the Alaskan coast from Point Barrow to Cape Krusenstern as shown in imagery acquired during March 1973 is shown in Figure 12. Compilation and analysis has made clear that the formation and persistence of shorefast ice is easily monitored with ERTS sequential imagery. If compiled in an atlas of shorefast ice distribution as a function of season, such data could be valuable in guiding the planning and construction of navigational and shore facilities.

APPLICATIONS ACHIEVED

The application of satellite imagery in describing and interpreting aspects of arctic and subarctic environments for proper utilization and management of earth resources was addressed in this investigation. ERTS imagery has been used to improve thematic mapping of estuarine processes, vegetation and geomorphic and geologic features. Major estuarine, circulation patterns, water masses, areas of sediment deposition and the distribution of tidal flats were identified and mapped in Cook Inlet. The distribution of permafrost terrain was mapped for a 153,400 km^2 area in north central Alaska. The methods employed were similar to those of previous work but the regional scale map produced had considerably greater detail. As a part of the permafrost mapping, more detailed surficial geology and vegetation maps were also made. These results will be directly applicable to route and site selection, particularly for the Nome to Kobuk Road in western Alaska. Permafrost mapping will also be useful in regional environmental interpretation and urban and land use planning, regulation and management in developing areas of Alaska. The location and monitoring of large river icings in northern Alaska was also accomplished and related to problems of route selection and regional planning.

The anticipated need for information on ice patterns and movements for purposes of navigation and construction of offshore facilities led to an analysis of sea and shorefast ice in the Arctic Ocean. The synoptic, regional perspective of ERTS imagery is well suited to the measurement of sea ice deformation. A spatial deformation analysis was done for a four day period in March 1973 which represents the first successful application of satellite imagery for this purpose. Shorefast ice accumulation and breakup along the western coast of Alaska was also mapped. The direct applications of ERTS imagery to an operational requirement of the Corps of Engineers was achieved in a concurrent investigation. The Corps of Engineers was required to institute a program for the inspection and inventory of dams throughout the United States as a result of public law 92-367, passed on 9 August 1972. In response to a request by the Office of the Chief of Engineers, members of this ERTS investigation team compiled and published a manual on "The Use of ERTS-1 Imagery in the National Program for the Inspection of Dams" (McKim, et al. 1972). This manual described a photointerpretation technique for identifying and inventorying water bodies six acres or larger with ERTS-1 imagery. The approach presented was clearly shown to be the most practical and economical method of accomplishing the requirements of the National Program for Inspection of Dams.

POTENTIAL APPLICATIONS

A number of potential applications of ERTS-1 imagery in a wide variety of earth resources studies have been recognized. These potential uses are directly applicable to the requirements of the Congressional Acts which form the basis for the principal civil works mission responsiblities of the Corps of Engineers. These Acts, listed according to subject area, are as follows:

1. Recreation
    - Federal Water Project Recreation Act, 1965
    - Land and Water Conservation Act, 1965
    - Outdoor Recreation Act, 1963
2. Environmental Impacts
    - National Environmental Policy Act, 1969

3. National Program for Inspection of Dams, 1972

4. Urban and Land Use Planning
    - Forest Conservation Act, 1960
    - Corps Urban Study Mission

5. Flood Plain/Inventory Mapping
    - Flood Plain Control Act, 1936-1960

6. Shore Line and Beach Erosion
    - River and Harbor Act, 1962 and 1968
    - Coastal Zone Management Act, 1972

7. Water Quality
    - Fish and Wildlife Coordination Act, 1946-1958
    - Federal Water Pollution Control Act, 1948-1972
    - Water Supply Act, 1958

Specific examples of ERTS investigations that contribute to work presently being performed under one or more of these Acts include: snow and ice surveys relating snowmelt to stream runoff and delineation of areas where ice creates engineering problem and hazards; floodplain mapping which will provide pertinent information in urban planning; monitoring aquatic pollution and relating the measured paramenter to land use practices; preparation of microzonation maps for seismic risk evaluations used in planning and guiding construction activities; compiling baseline data for maritime projects and coastal zone management programs; and in the interpretation of coastal processes. The results obtained from these remote sensing investigations can be used in conjunction with information acquired by conventional means in developing improved data collection procedures.

SUMMARY AND RECOMMENDATIONS

The ERTS-1 mission provides for the first time a means of analyzing terrestrial and marine phenomena on a regional basis. Previously these analyses were not feasible because of expense or lack of suitable data. Improved synoptic mapping of estuarine, surface circulation patterns, suspended sediment distribution and water mass boundaries has been accomplished in Cook Inlet. Also more detailed surficial geology and vegetation maps were prepared at a scale of 1:1,000,000 for a 153,400 km^2 area of north-central Alaska. Based on the interpretation of surficial geology and the probable depth of thaw inferred from vegetation associations, a permafrost terrain map of the same area was prepared with considerably greater detail than previously available maps. Several large river icings were monitored along the proposed Alaskan pipeline route from Prudhoe Bay to the Brooks Range. Sea ice deformation and drift northeast of Point Barrow were measured during a four day period in March. Shorefast ice accumulation and ablation along the west coast of Alaska was mapped for the spring and early summer seasons. In addition applications have been developed in all phases of this investigation and potential uses proposed.

Based on the experience of this investigative team, it is considered appropriate to make some general recommendations on future NASA satellite applications programs. First, ERTS-1 should be fully utilized as long as it is operational. Consideration should be given to delaying the ERTS-2 mission until its sensor package can be significantly improved or augmented. Second, there is a need to emphasize and improve provisions for technology transfer within user organizations. Greater awareness and participation from the operational personnel of user agencies is needed. This is a responsibility of the user agencies but NASA should take the lead in stimulating a greater awareness of this requirement. Third, a provision for direct downlink for users of DCP's would enhance the utility of this system for many present and potential users by streamlining the data handling system. Finally, the logical culmination of the ERTS program would be the establishment of geostationary, operational satellites, as has been proposed in the GOES program. The geostationary satellites should include, among other sensors, high resolution MSS sensors, directable zoom capability for coverage of localized phenomena, and a direct downlink for a data collection system.

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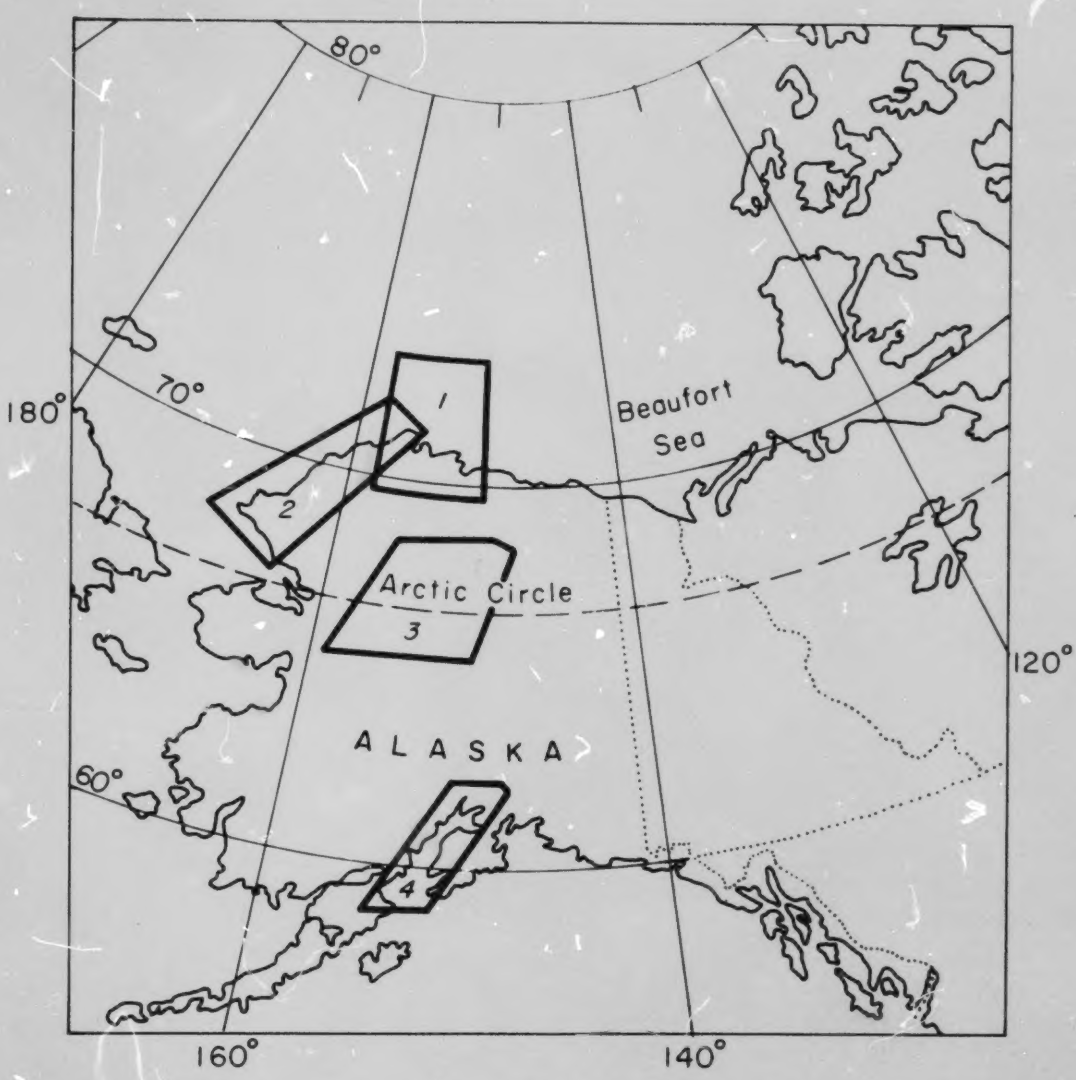
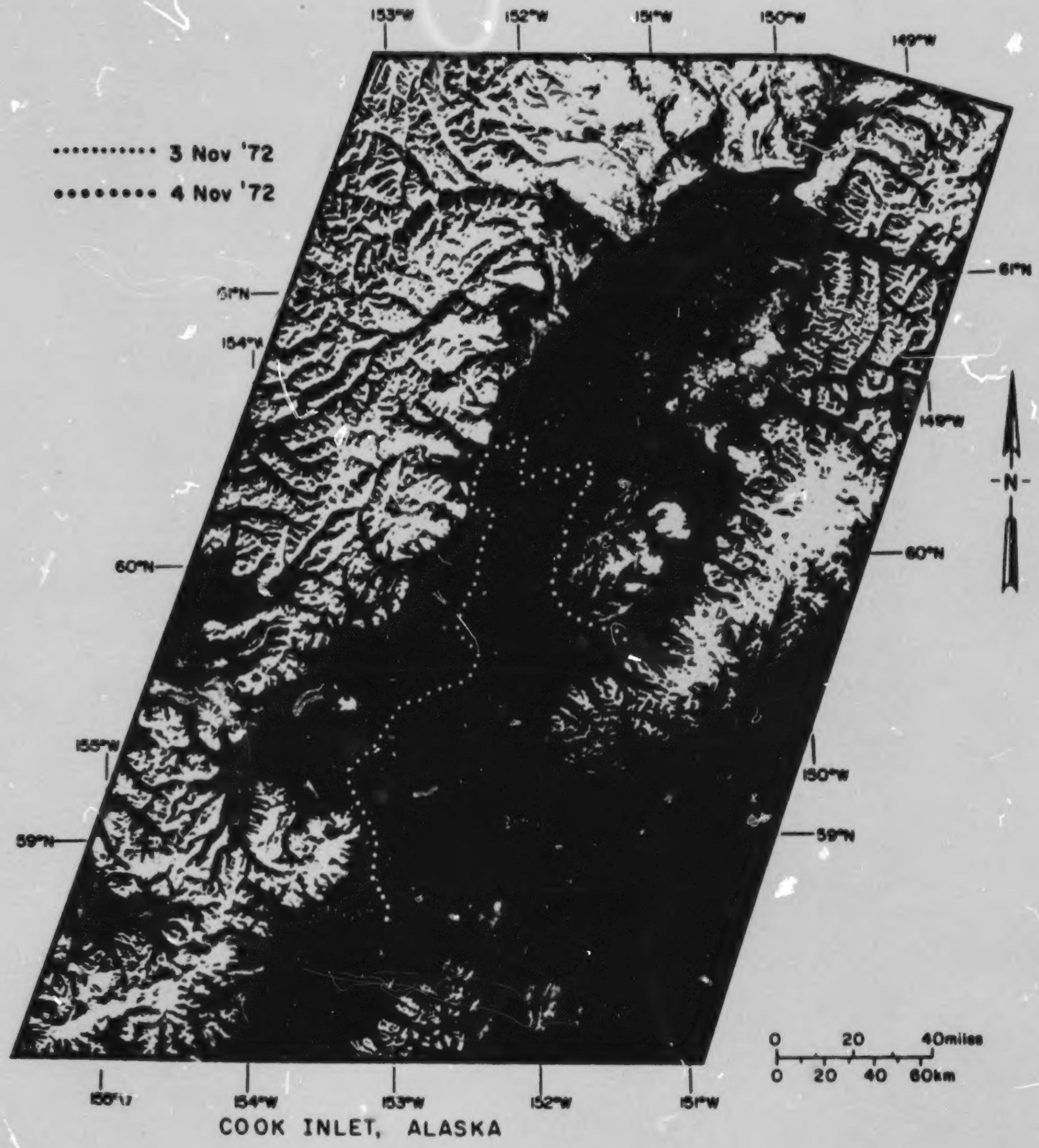

80°
70°
180°
1
2
Beaufort Sea
Arctic Circle
3
120°
ALASKA
60°
4
160°
140°

Fig. 1 Site Location Map.


153°W
152°W
151°W
150°W
149°W
··········· 3 Nov '72
●●●●●●●● 4 Nov '72
61°N
154°W
60°N
155°W
59°N
61°N
149°W
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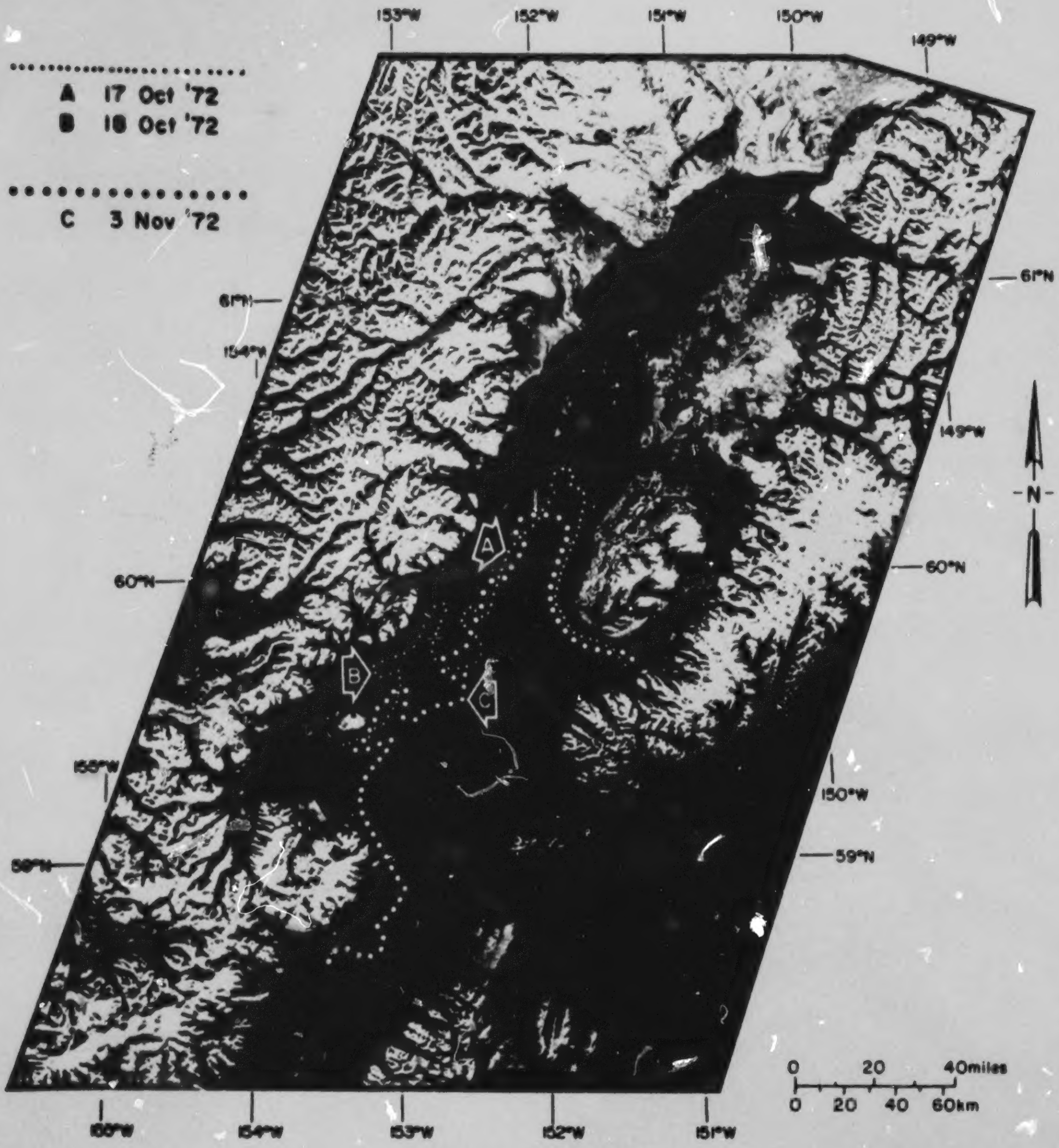
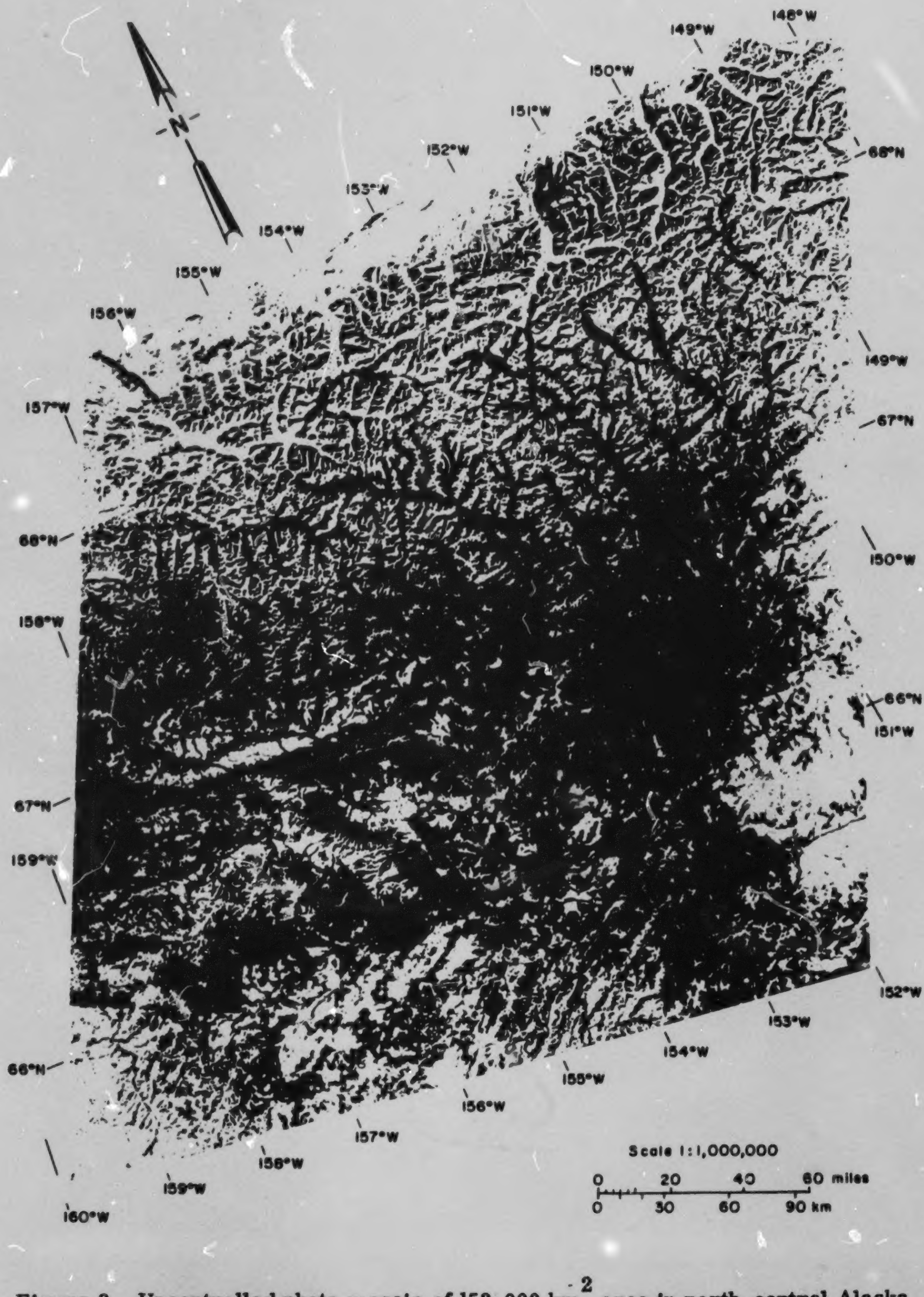
59°N
N
0 20 40 miles
0 20 40 60 km
155°W
154°W
153°W
152°W
151°W
COOK INLET, ALASKA

a. Daily changes.

Figure 2. Boundaries separating oceanic and inlet water (from Anderson, et al., 1973).


A 17 Oct '72
B 18 Oct '72
C 3 Nov '72
153°W
152°W
151°W
150°W
149°W
61°N
154°W
149°W
N
60°N
60°N
155°W
150°W
59°N
59°N
A
B
C
0
20
40miles
0
20
40
60km
155°W
154°W
153°W
152°W
151°W

b. Changes over 18-day period.
Figure 2. (Continued)


N
148°W
149°W
150°W
151°W
152°W
153°W
154°W
155°W
156°W
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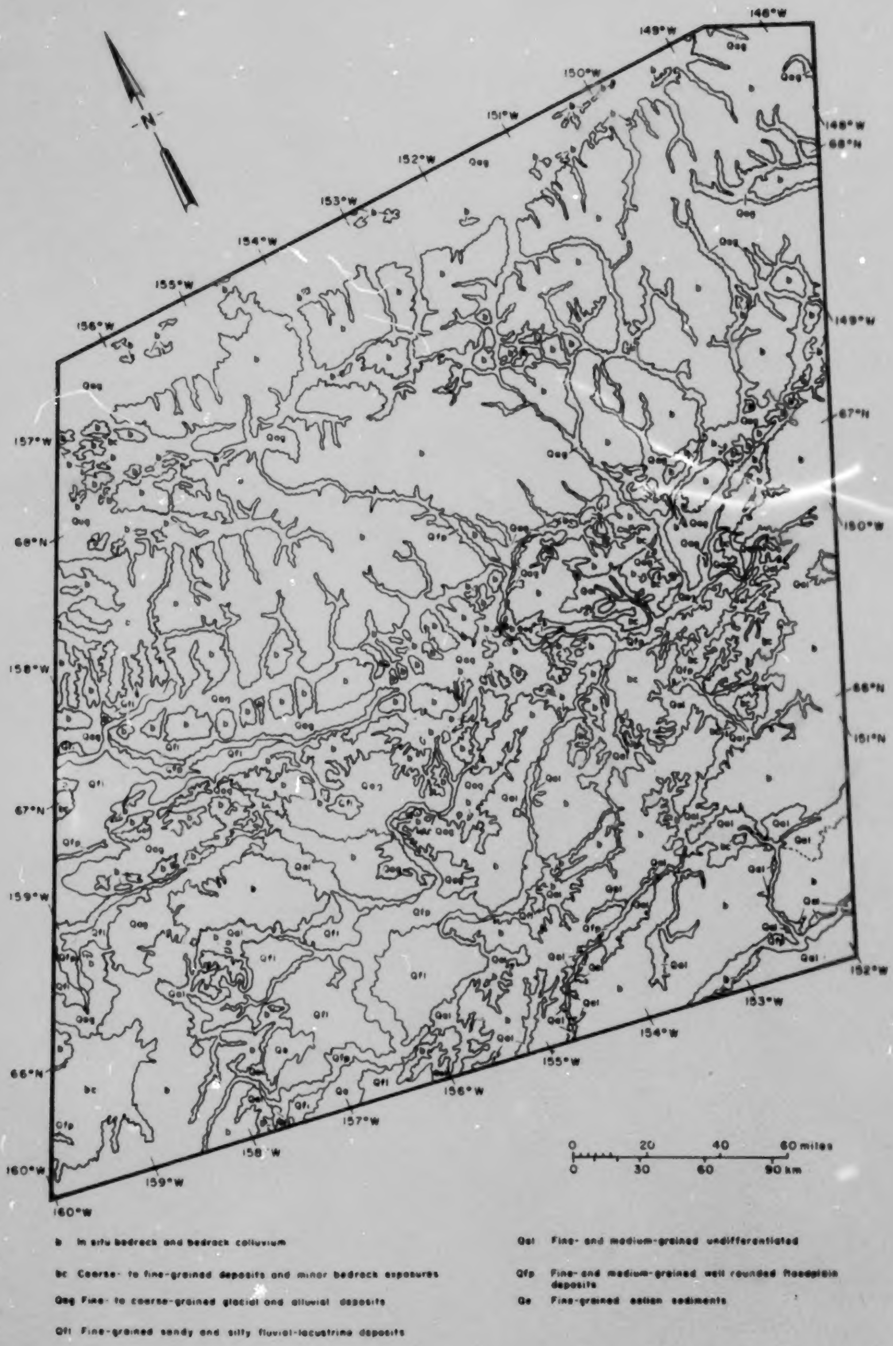
68°N
158°W
67°N
159°W
66°N
160°W
68°N
149°W
67°N
150°W
66°N
151°W
152°W
153°W
154°W
155°W
156°W
157°W
158°W
159°W
Scale 1:1,000,000
0 20 40 60 miles
0 30 60 90 km

Figure 3. Uncontrolled photo mosaic of 153,000 km^2 area in north-central Alaska .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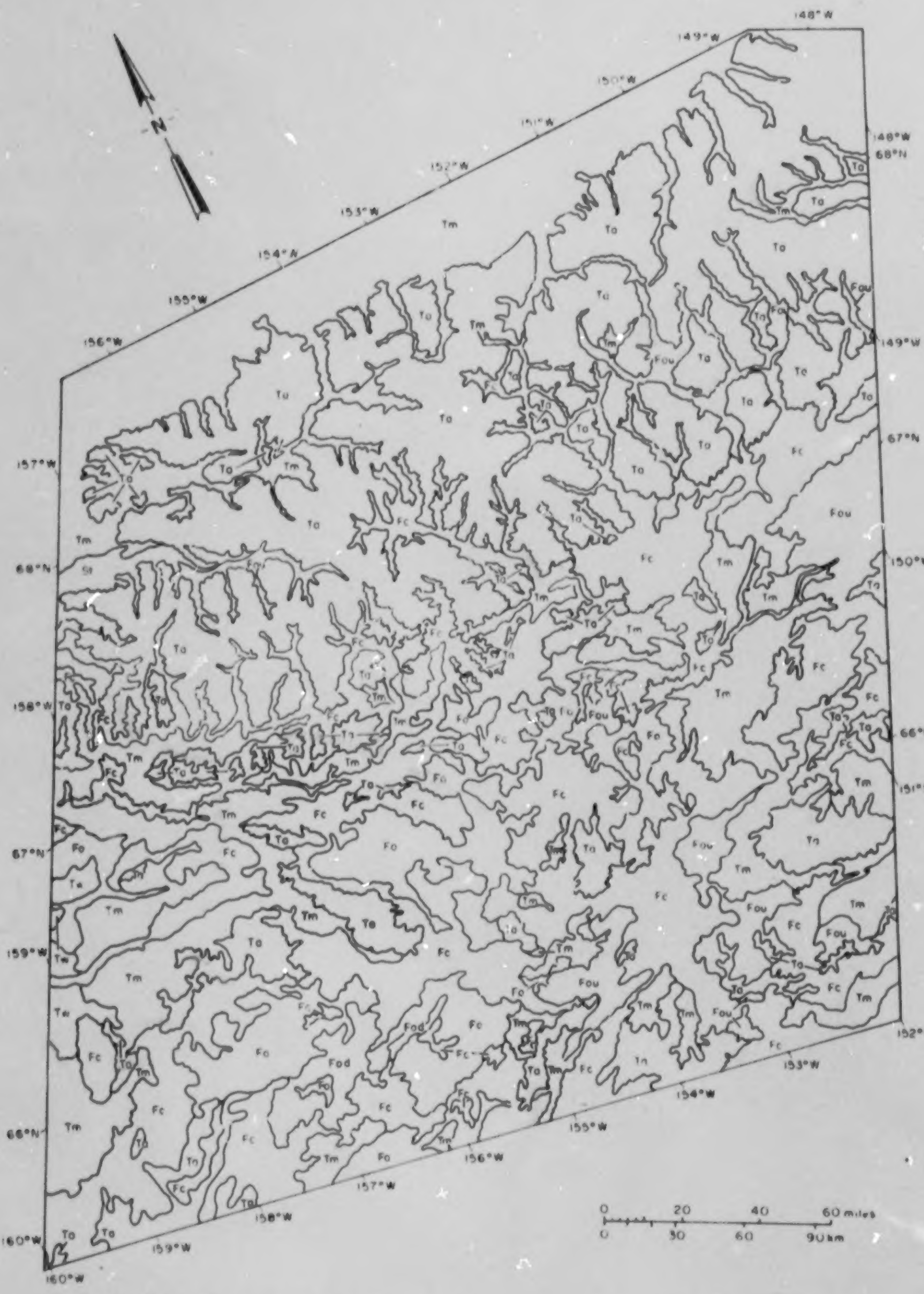
157°W
158°W
159°W
160°W
68°N
67°N
66°N
Qag
Qfl
Qfp
Qal
Qe
bc
b
0 20 40 60 miles
0 30 60 90 km
b In situ bedrock and bedrock colluvium
bc Coarse- to fine-grained deposits and minor bedrock exposures
Qag Fine- to coarse-grained glacial and alluvial deposits
Qfl Fine-grained sandy and silty fluvial-lacustrine deposits
Qal Fine- and medium-grained undifferentiated
Qfp Fine- and medium-grained well rounded floodplain deposits
Qe Fine-grained eolian sediments

Figure 4. Surficial geology map of north-central Alaska.


N
148°W
149°W
150°W
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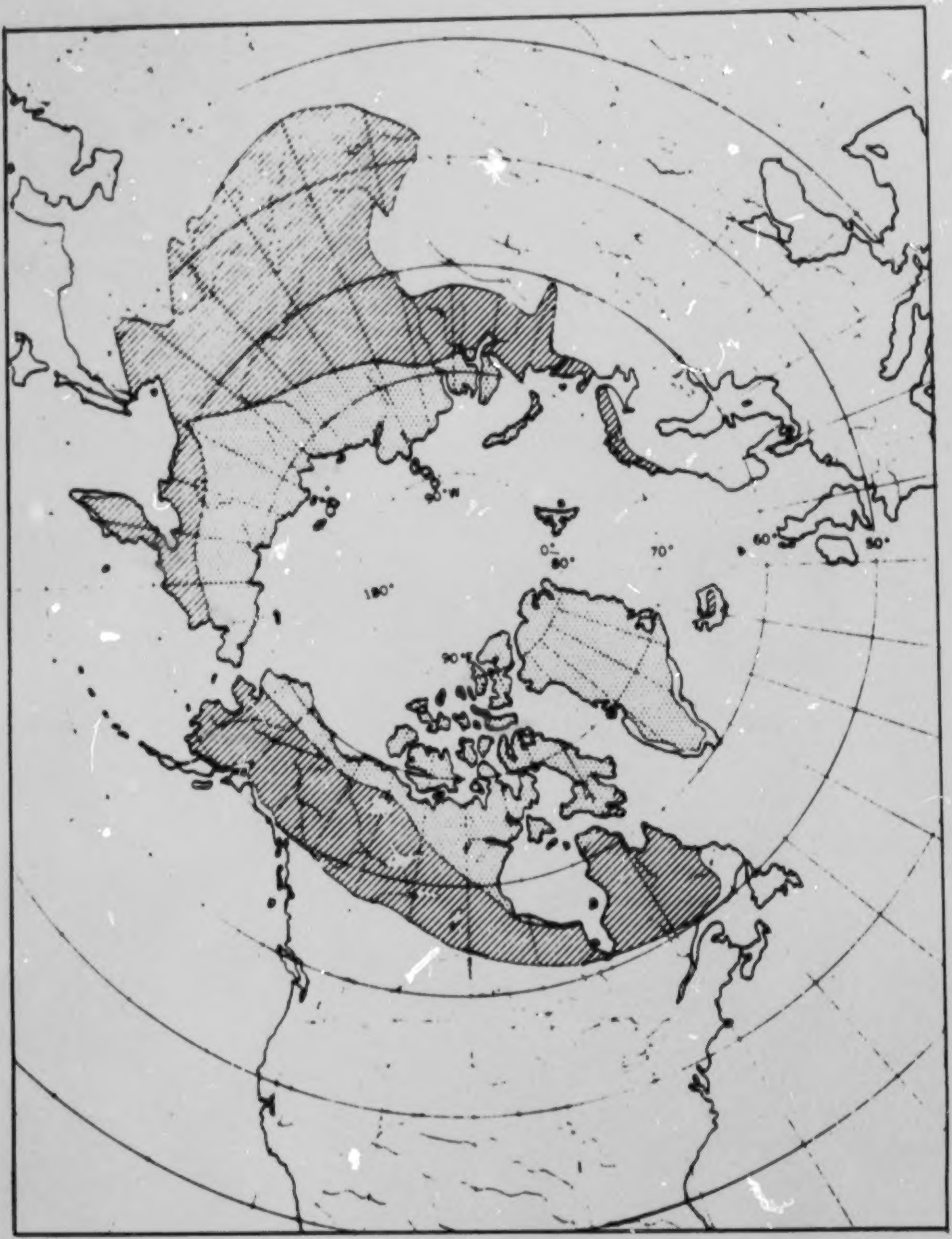
154°W
155°W
156°W
157°W
158°W
159°W
160°W
68°N
67°N
66°N
0 20 40 60 miles
0 30 60 90 km
Ta
Tm
Fc
Fou
Fo
Fod
St
Tw

Fc	Tall to moderately tall, closely spaced spruce-hardwood forest
Fou	Forest association as in Fc, but less dense
Fo	Open, stunted, black spruce forest, also including tamarack, white birch and white spruce, mosses and grasses.
Fod	Open black and white spruce forest, sand dune areas
Tm	Moist tundra. Some stunted black spruce, cotton-grass tussocks dominant. Sedges and small shrubs
Tw	Wet tundra. Sedge and cottongrass, few woody plants
Ta	Alpine tundra. Primarily barren, but locally dominated by low heath shrubs, dwarf herbs and prostrate willows.
St	Shrub thickets. Alders, willows, blueberries, other woody berry shrubs

Fig. 5. Vegetation map of north-central Alaska.



90°W
0°
80°
70°
60°
50°
180°
90°E

Figure 6. Geographic distribution of permafrost: stipled area is continuous permafrost zone: lined area is discontinuous permafrost zone (from Ferrians, 1969).

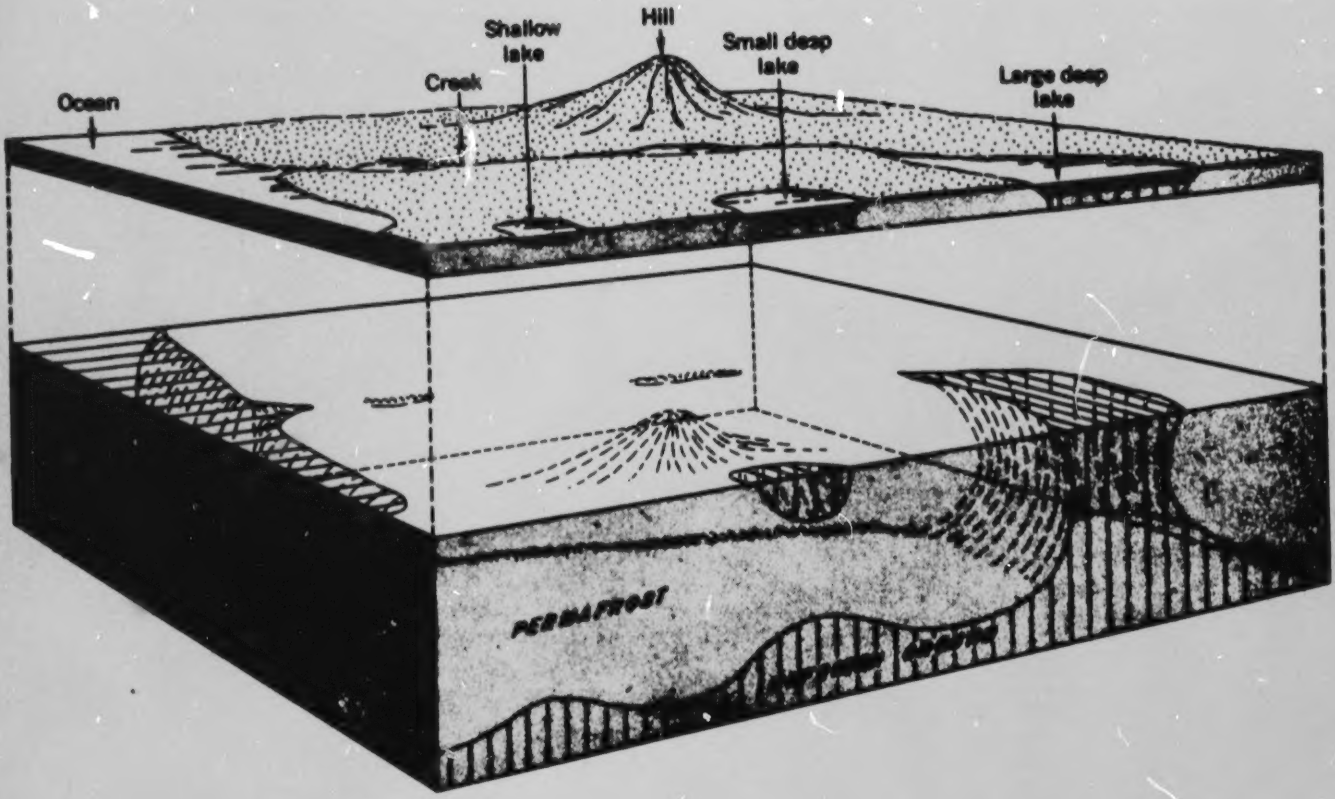

Ocean
Creek
Shallow lake
Hill
Small deep lake
Large deep lake
PERMAFROST

Figure 7. The effect of surface features on the distribution of permafrost in the continuous permafrost zone (after Lachenbruch, 1968, p. 837).

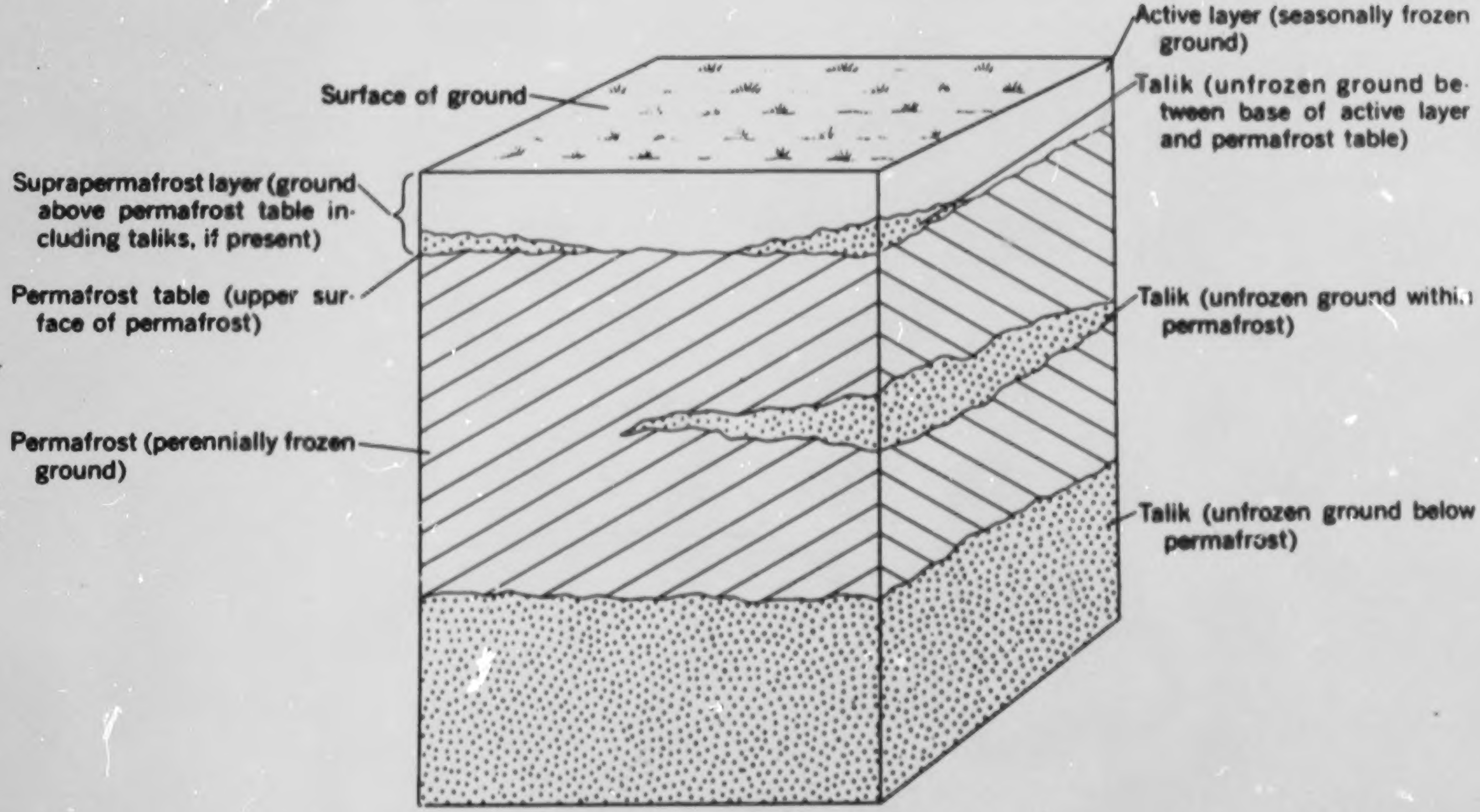

Active layer (seasonally frozen ground)
Surface of ground
Talik (unfrozen ground between base of active layer and permafrost table)
Suprapermafrost layer (ground above permafrost table including taliks, if present)
Permafrost table (upper surface of permafrost)
Talik (unfrozen ground within permafrost)
Permafrost (perennially frozen ground)
Talik (unfrozen ground below permafrost)

Figure 8. Occurrence of taliks in relation to the active layer, supra-permafrost zone, permafrost table, and permafrost (from Ferrians, et al, 1969).

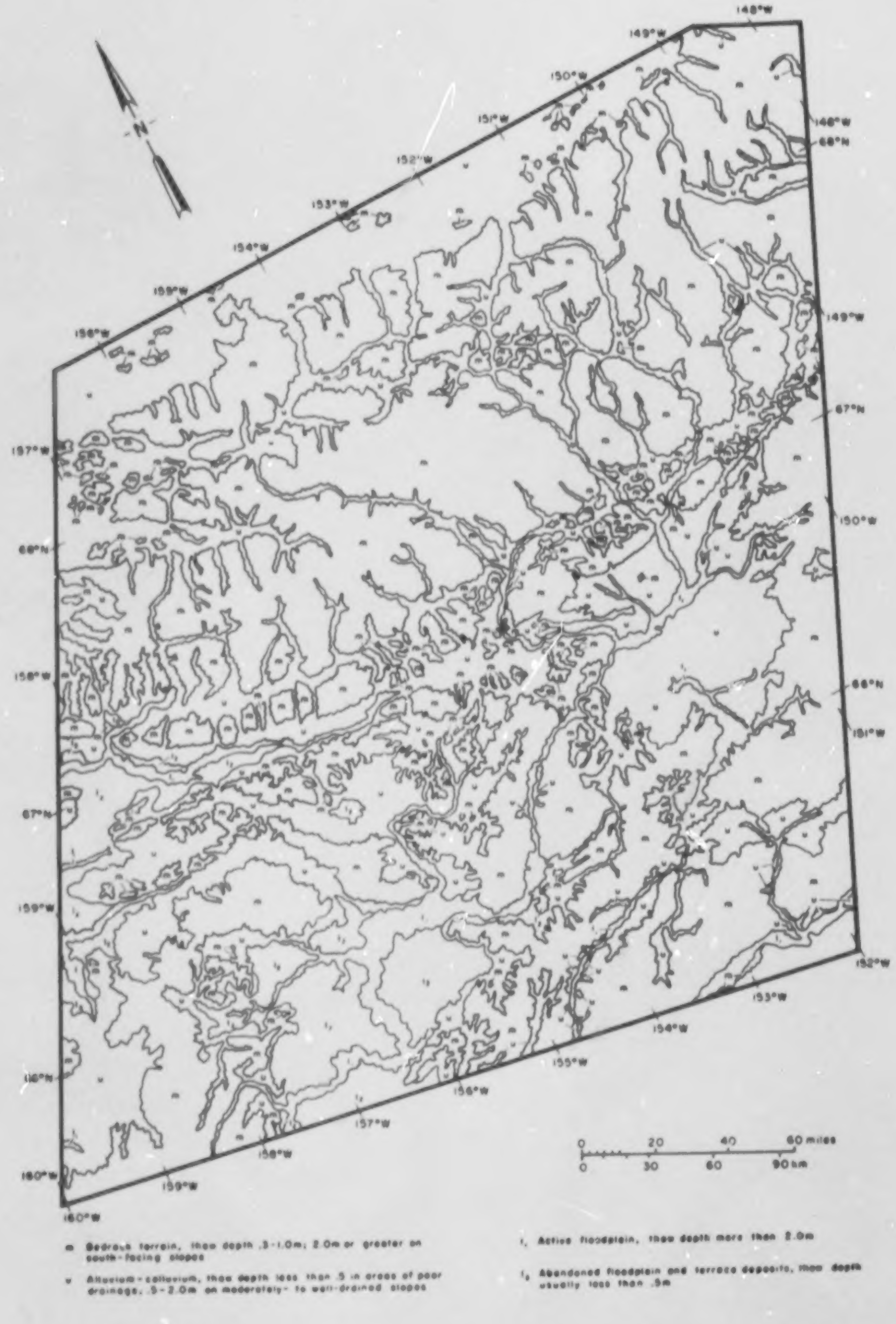

N
148°W
149°W
150°W
151°W
152°W
153°W
154°W
155°W
156°W
157°W
68°N
158°W
67°N
159°W
66°N
160°W
148°W
68°N
149°W
67°N
150°W
66°N
151°W
152°W
153°W
154°W
155°W
156°W
157°W
158°W
159°W
160°W
0 20 40 60 miles
0 30 60 90 km
m Bedrock terrain, thaw depth .3-1.0m; 2.0m or greater on south-facing slopes
u Alluvium-colluvium, thaw depth less than .5 in areas of poor drainage, .5-2.0m on moderately- to well-drained slopes
f1 Active floodplain, thaw depth more than 2.0m
f2 Abandoned floodplain and terrace deposits, thaw depth usually less than .5m

Figure 9. Permafrost terrain map of north-central Alaska.

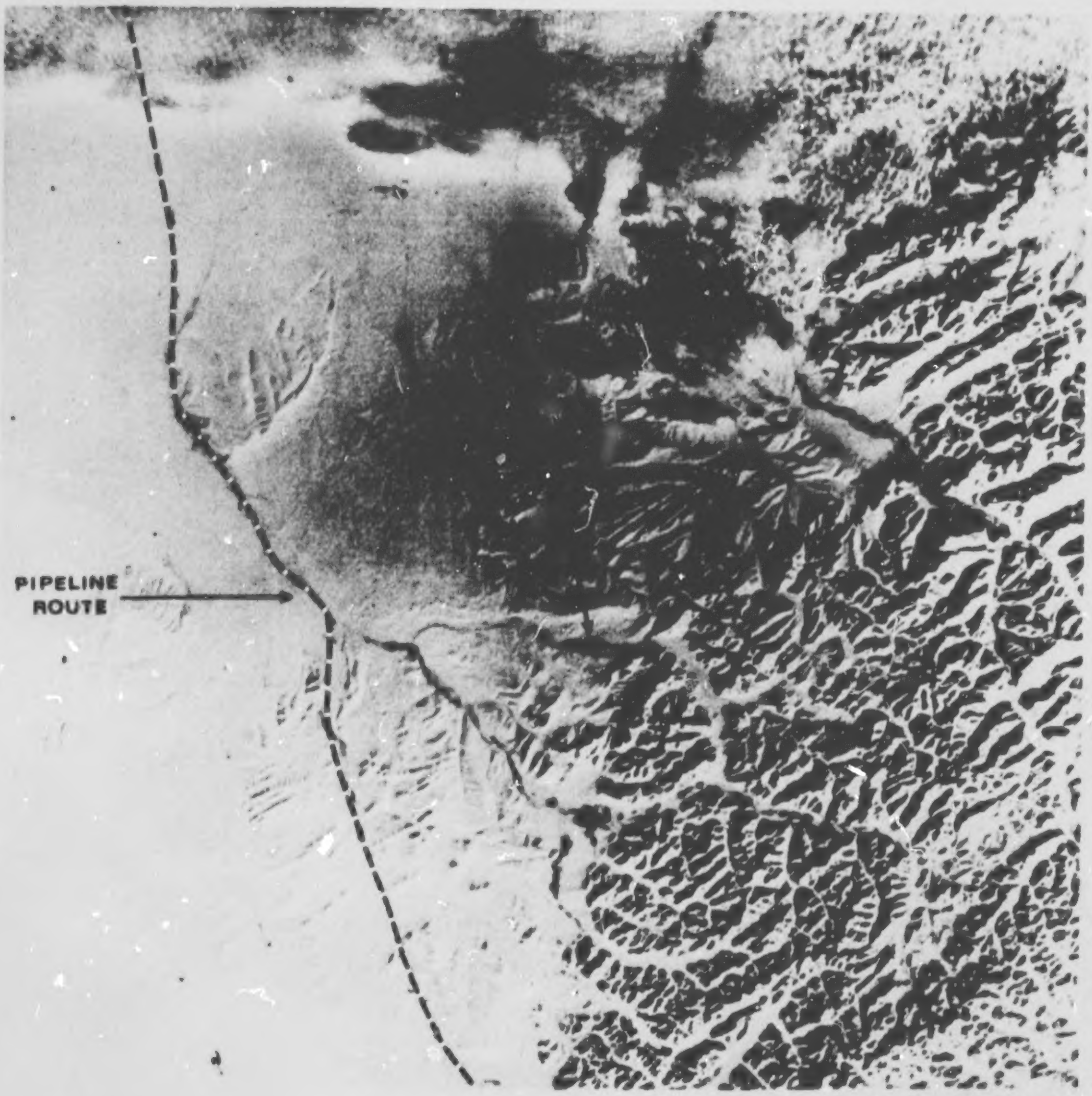
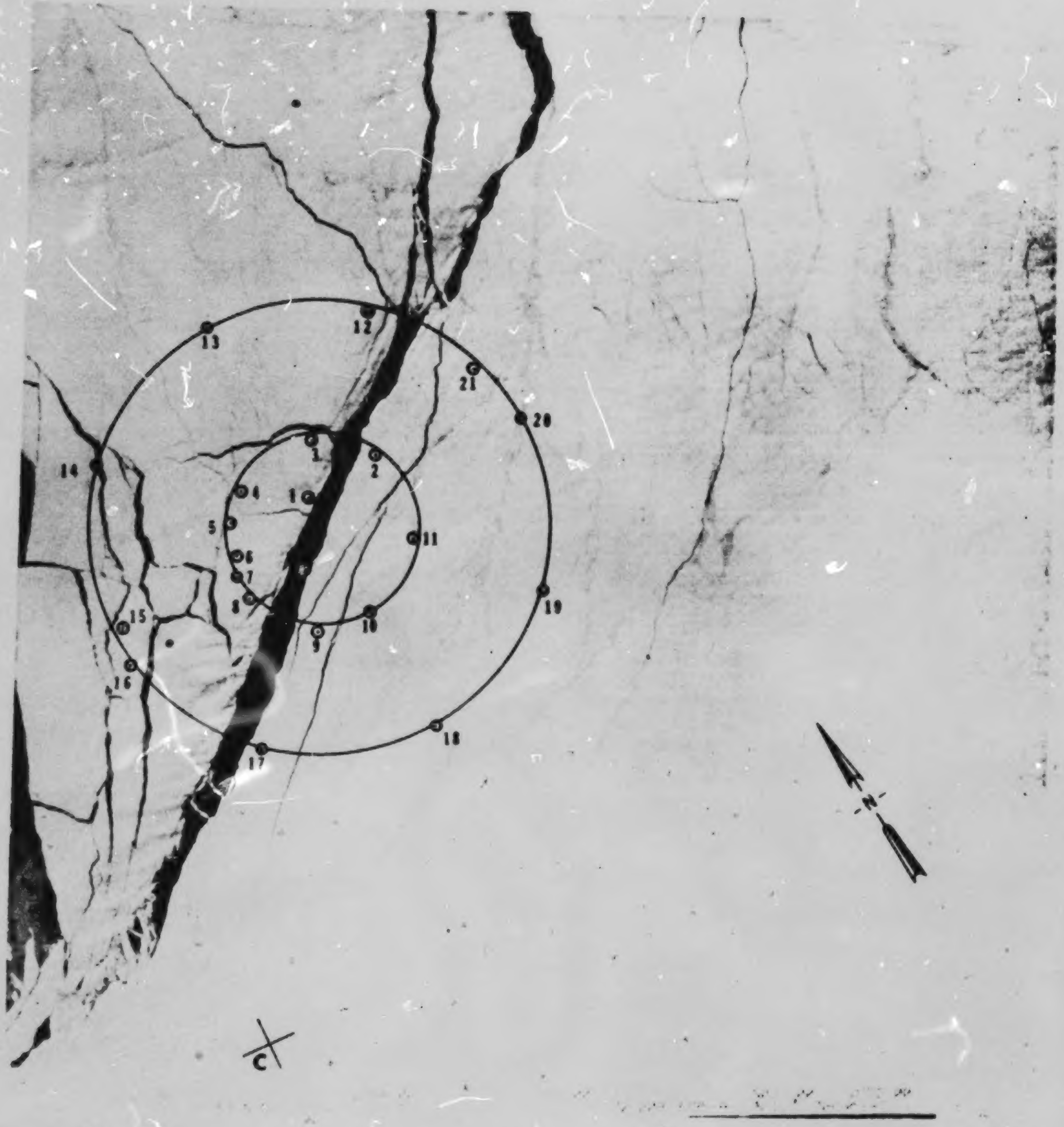
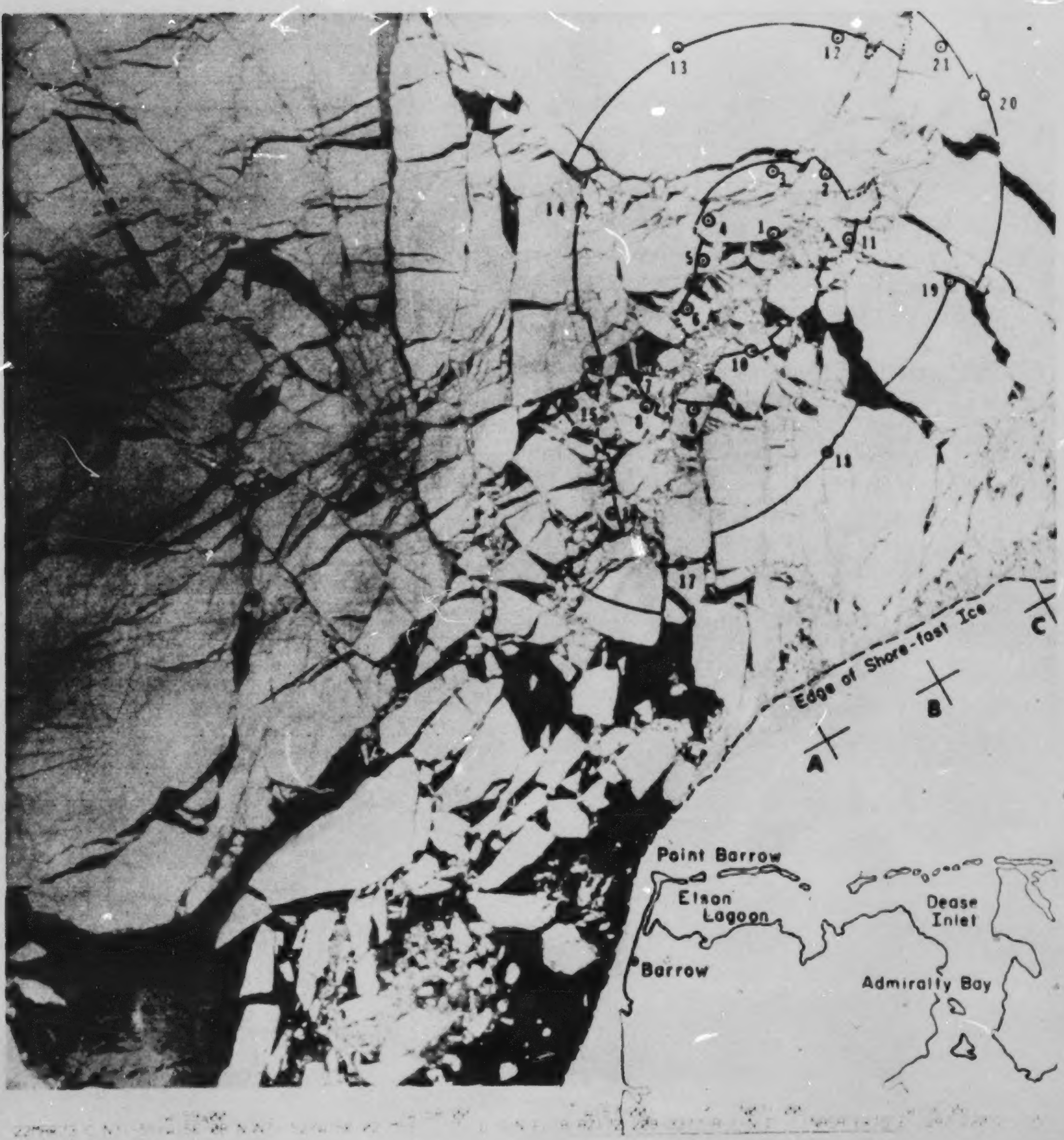

PIPELINE ROUTE

Figure 10. Proposed pipeline route in relation to known icings (ERTS MSS band 7 image, 1251-21123).


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
N
C

a. Nested strain arrays shown on ERTS MSS band 7 scene 19 March 73.

Figure 11. Arctic ice pack northeast of Point Barrow, Alaska (Crowder, et al., 1973).


13
12
21
20
14
2
3
1
11
4
5
19
6
10
7
15
8
9
18
17
Edge of Shore-fast Ice
A
B
C
Point Barrow
Elson Lagoon
Dease Inlet
Barrow
Admiralty Bay

b. Deformation and drift strain of nested strain arrays on March 73 scene.

Figure 11. (Continued)

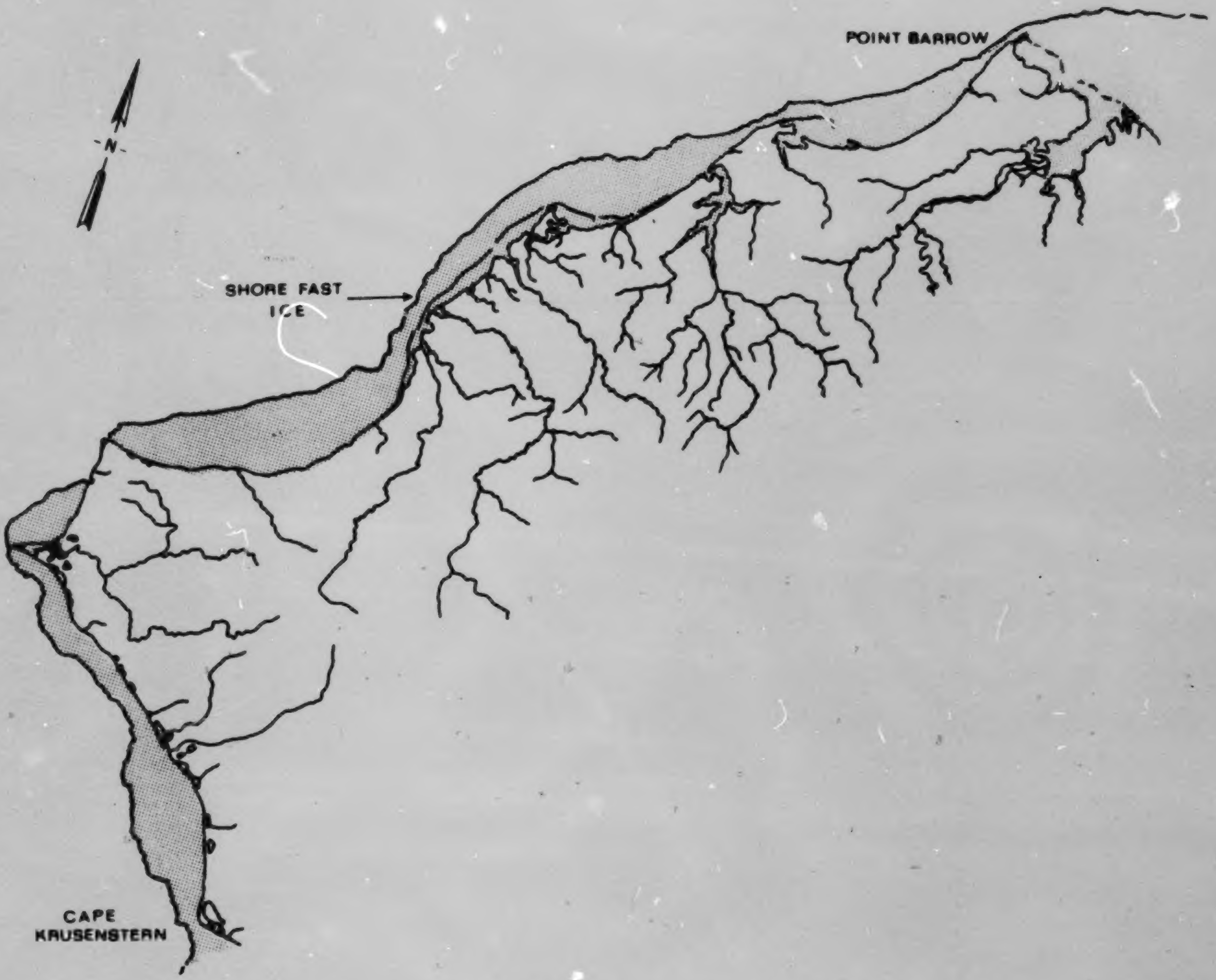

N
POINT BARROW
SHORE FAST ICE
CAPE KRUSENSTERN

Figure 12. Shore fast ice from Point Barrow to Cape Krusenstern (March imagery).

ALASKA

Vocabulary - Define the following terms in detail.

- Estuarine
- Geologic
- Vegetation
- Synoptic
- Permafrost
- Inlet
- Ice
- Saline
- Upwelling
- Glaciofluvial
- Icings
- Sea Ice
- Shore Ice
- Suspended Sediment

Questions - Answer the following inquiries in detail.

1. What are two of the problems in research concerning Alaska?
2. Discuss the Alaskan pipeline and include all parameters?
3. How is ERTS imagery advantageous to Alaskan data gathering?
4. How is sediment a problem in the Knik, Matanuska, Susitna, Beluga, MacArthur, Drift, and Tuydens **Rivers** as they flow to the inlet?
5. Why do oil spills hardly ever reach shore in Alaska, especially near the Drift, Arness or Nikiski Rivers?
6. What is the main reason for the oceanic and fresh water boundary at Cook Inlet?
7. What are the surficial geology classifications in north-central Alaska?
8. Why is vegetation an important indicator of permafrost?
9. Explain permafrost.
10. Explain permafrost and its relationship to the oil pipeline?
11. What are major acts and their implications on ERTS-1 imagery?

Discussion Topics

1. What are the major biological considerations in the placement and construction of the Alaskan Pipeline?
2. Explain glacier movement and any run off factors.

WATER-MANAGEMENT MODELS IN FLORIDA FROM LANDSAT-1 DATA

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ABSTRACT

A prototype data acquisition and dissemination network, installed and operated by the U. S. Geological Survey, is a viable approach for providing the near real-time data needed to solve hydrologic problems confronting the nearly 2.5 million residents of southern Florida. Water-stage and rainfall data from ground stations are transmitted from the Everglades via LANDSAT, the NASA tracking stations, and the U. S. Geological Survey to the users in less than 2 hr, a significant improvement over conventional techniques requiring up to 2 months. LANDSAT imagery significantly enhances the utility of the ground station measurements. Water stage (depth) is correlated with water-surface areas from the imagery to obtain water stage-volume relations in near real-time for management decisions concerning the distribution of water to the people, fauna, and flora of southern Florida.

INTRODUCTION

The water supply for southeastern Florida, with a population of more than 2.5 million, including the Everglades National Park, depends on the management of water within the Everglades basin (Figure 1). Decisions affecting the control of this supply are based on water budgets developed primarily from hydrologic data acquired and analyzed by the U. S. Geological Survey as part of their program of hydrologic investigations and data collection network.

The goal of this investigation is to evaluate the usefulness of LANDSAT in improving the overall effectiveness of this collection and dissemination network. Resulting network improvements in data timeliness and accuracy would have a direct beneficial impact on the water distribution to the people, fauna, and flora of southern Florida. To accomplish this goal, the Geological Survey used imagery from the LANDSAT Multispectral Scanner (MSS) and the LANDSAT Data Collection System (DCS) to evaluate their utility in supporting near real-time hydrologic data acquisition and dissemination. This paper reports on the work accomplished and results achieved in establishing and operating this prototype network.

MANAGING THE WATER SYSTEM

The storage and flow of water in southeastern Florida is controlled by the Central and Southern Florida Flood Control District, which maintains and operates a system of levees, canals, control structures, pumping stations, and water storage areas. The control of this system (ref. 1) is based on water budgets developed from hydrologic data collected and disseminated primarily by the Geological Survey.

The levees retain water in four major impoundment areas (Figure 2); (1) Lake Okeechobee, (2) Conservation Area 1, (3) Conservation Area 2, and (4) Conservation Area 3. Shark River Slough (Figure 2), a water-course important to the environment of Everglades National Park, at the downstream end of these interconnected water bodies, also depends on overland flow from adjoining Conservation Area 3.

The four major impoundment areas impede the normal surface water flow from the Everglades and Lake Okeechobee through agricultural and urban areas during the rainy season, June through October. Pumping stations at the edges of the three conservation areas provide flood protection by pumping excess rainfall from the Everglades agricultural area and other flood-prone areas into Lake Okeechobee and the three conservation areas. Thus, the system not only provides flood protection, but also enhances water conservation. Water is transferred from the conservation areas into Everglades National Park or to coastal cities as needed through a network of surface canals.

Canals also drain the urbanized zone along the coast. They transfer water from Lake Okeechobee and the conservation areas to the Everglades agricultural area and to the east coast to replenish ground-water reservoirs near municipal well fields and to prevent seawater intrusion. Flow in the canals is regulated by coastal control structures which are normally open or partly open during the rainy season. The structures are generally closed during dry seasons to prevent inland movement of salt water and overdrainage of fresh water.

Scheduled releases from the conservation areas are made during the year to sustain plants and animals in Everglades National Park. Late in the dry season, water is also released from the conservation areas to the canals, as required, to maintain water levels near the coast and to replenish well fields. During much of the dry season, eastward flow in canals is maintained by water seeping under the levees of the water conservation areas, however, water in the canals is not discharged to the ocean; rather it infiltrates the Biscayne aquifer near the coast. During prolonged drought, some water can be transferred directly from Lake Okeechobee through the conservation areas to points of need along the coast. Usable storage in the lake is usually shared by municipalities, agricultural interests, and the Everglades National Park.

WATER BUDGET

Management decisions as to where and when to store and release water from the impoundments are based on an accounting of the amount of water in surface storage. This accounting procedure (refs. 2 and 3) relates basin water inputs and outputs as modeled in Figure 3 and results in a water budget for the area.

Monthly water budgets for Lake Okeechobee and the three conservation areas are computed by the Central and Southern Florida Flood Control District and the U. S. Army Corps of Engineers. Two budgets are prepared; one for a condition of normal rainfall for the remainder of the dry season and the other for a condition of last year's rainfall for the same period.

The budget inputs (Figure 3) include surface flow into the basin (inflow) and rainfall on the basin. The outputs are the combined losses: evaporation transpiration (water released to the atomosphere as part of the life process of vegetation), surface water seepage into ground water reservoirs, and the canal outflow for irrigation and municipal supply. Subtracting output from input, as shown in the model of Figure 3, gives a surplus or a deficiency in the water storage for a specified storage area and time.

Several water budget studies for the conservation areas by Federal (U.S. Corps of Engineers) and State water-management agencies (Central and Southern Florida Flood Control District) are underway.

The major problem in developing a good water budget is to adequately measure the input and output quantities. Another task is to determine the water in storage in the conservation areas. This is difficult because of the large area extent and shallowness of water which makes representative stage recordings difficult to obtain. A good budget analysis requires large amounts of accurate and timely hydrologic data. It is this data need which the hydrologic data network is designed to satisfy.

HYDROLOGIC DATA NETWORK

Hydrologic data used in developing water budgets are collected and disseminated (ref 4) in southeastern Florida by the U.S. Geological Survey, as part of the nationwide hydrologic data network. The network is operated by the Survey in cooperation with local, State, and other Federal agencies; the Survey gathers data on a wide variety of environmental parameters. In the Everglades alone, more than 100 gaging stations provide daily records of water surface elevation or flow. Nationwide, the Geological Survey has nearly 18,000 such stream-gaging stations, of which approximately 10,000 have digital water stage recorders. These small field instruments continuously monitor stream stage via linkage to a float in a stream-connected stilling well. Periodically, at 15-, 30-, or 60-minute intervals, the recorder punches the real-time stage value on a 16-channel paper tape, a machine-readable record.

Without the advantage of LANDSAT-DCS, data from a particular field instrument are retrieved by field engineers and technicians who visit the station about once a month, calibrate the instrument, perhaps take supplementary measurements and samples, and conduct general maintenance. The data, many of which are in machine-readable form, are returned to the office, checked for quality control, transferred onto punch cards or magnetic tape for entry into the computer system, analyzed, plotted and disseminated to users. Time from data recordings to dissemination to users is about 2 months after initial recordings. These long delays reduce the utility of the data for current water budgets and, consequently, delay management decisions affecting the storage and flow of water. The need to reduce the time required to develop water budgets is becoming increasingly important in Florida, as in other areas of the Nation, where water managers are attempting to satisfy the water demands of an ever-increasing population while still retaining sufficient water in the system to meet the needs of the aquatic environments and upgrade and maintain the water quality in the water-storage areas, canals, and aquifers.

The Geological Survey, in addition to disseminating hydrologic data to users in southern Florida, also stores the data in the national water data storage and retrieval system (ref. 5) in Washington, D.C. and Reston, Virginia. From this system the data are made available nationwide. Survey offices, such as the Miami office, are interlinked with the national water data storage and retrieval system by means of a national telecomputing system which provides general data processing support for the national water data storage and retrieval system. The national telecomputing network consists of the computer centers in Washington, D.C. and Reston, Virginia, and nearly 100 remote computer terminals in Survey offices across the Nation, one of which is in the Miami office. The Washington, D.C. computer center has an IBM 360/65 computer and the National Center at Reston, Virginia has an IBM 370/155 computer.

Thus, the major hydrologic activities of the Geological Survey, the collection, storage, retrieval, and analysis of hydrologic data are accomplished through the operation of three basic systems: the hydrologic data network, which provides data collection; the national water data storage and retrieval system, which processes and stores data generated by the hydrologic data network; and a national telecomputing system, which provides general data processing support for the national water data storage and retrieval system.

RESULTS AND DISCUSSION

To achieve the goals of the investigation, the Geological Survey analyzed both LANDSAT-MSS imagery and in situ monitoring by LANDSAT-DCS in order to evaluate their separate and combined capabilities in the Hydrologic Data Network. Paulson (refs 5 and 6), Schumann (ref 7), and Cooper (ref 8) applied similar techniques to operational systems with a DCS capability and Graybell (ref 9) and Deutsch (ref 10) used MSS to determine surface-water distribution. Anderson (ref 11) used the MSS imagery to identify and map vegetative communities within wetlands. Reeves (ref 12) used successive passes of LANDSAT imagery of playa lakes in the Texas high plains to demonstrate the dynamics of surface-water distribution within the lakes. However, the investigation described herein combines an operational LANDSAT data-collection system with the LANDSAT multispectral scanner data.

Twenty data collection platforms (DCPs) were established in southern Florida. Water-level and rainfall data collected and disseminated in near realtime (less than 2 hours) from these instruments, were also analyzed in conjunction with LANDSAT imagery enhanced by electronic processing. Results reported in this section show that the combined use of MSS and DCS data provides more benefits than the use of either technique alone.

LANDSAT - DATA COLLECTION SYSTEM

The LANDSAT Data Collection System (DCS) is a communications system (ref 13) that consists of three elements: a small low-powered battery-operated radio transmitter called a data collection platform (DCP), a radio transponder aboard the LANDSAT satellite, and ground-receiving sites. The polar-orbiting LANDSAT makes about 14 orbits of the earth daily and can relay data from a DCP to a ground-receiving site whenever both are mutually visible from LANDSAT, this occurs during a brief period on each of several orbits. The DCP transmits a brief data message of 0.04 sec in duration once every 90 or 180 seconds and can communicate with the satellite during several mutually visible periods daily. The number of mutually visible periods is primarily a function of geographical position and local terrain interference. Two ground-receiving sites; one at the Goddard Space Flight Center in Greenbelt, Maryland; the other at Goldstone, California, provide good coverage for the contiguous 48 states. They receive data from continental American DCPs on 3 to 7 daily orbits during mutual visibility periods lasting 12 to 14 minutes per orbit.

Data Collection Platform - Twenty DCPs were established in the Everglades (Figs. 4, 5, 6, and 7) and Big Cypress Swamp to the west to transmit water level and rainfall. The flow of data from the area to the Geological Survey office in Miami starts with the water-level and rainfall gages at the DCP.

Housed at the DCP shown in Figure 6 are the DCP (ref 14), water-stage recorder, rainfall recorder, and timer and power supply for both recorders.

Before the DCP transmits the data to the satellite, it receives the data from a sensor (recorder) and then encodes and puts the data into a form for radio transmission. Although the DCP normally transmits a signal every 3 min, the DCP can be set to transmit every 90 seconds. When the LANDSAT satellite (Figure 8) is in mutual line of sight of a DCP and a NASA receiving station, the data transmitted from the DCP is received by the satellite and transmitted to NASA receiving stations at Goddard or at Goldstone. In southern Florida, this mutual communication occurs from 3 to 6 times per day. Each time, 1 to 4 distinct messages can be transmitting every 3 minutes.

At the receiving station, the data are decoded and sent by NASA communication line to the Operations Control Center and then to the NASA Data Processing Facility at Goddard. At the processing facility, the data are verified and put in a form to be teletyped to Miami. The data are received by teletypewriter as perforated tape and printout. The total elapsed time from field measurement to printout in Miami is about 45 minutes.

From the teletypewriter, the data are fed into a programmable calculator, which analyzes the data and produces the finished product, which is telecopied to the water-management agencies on the same day.

On an average day, data are received in Miami 2 or 3 times each morning and 2 or 3 times each night. At future stations where parameters such as wind-speed are to be monitored, data will be required more frequently.

Handling of DCS Data. - After data are received in Miami by teletypewriter, the perforated tape from the teletypewriter is fed into the calculator through a tape reader. Equipment available in the Miami office include the programmable calculator, thermal printer, paper tape reader, x-y plotter, hopper card reader, cassette memory recorder, extended memory, and acoustic coupler. The cassette memory recorder allows data and programs to be stored outside the programmable calculator. The extended memory is an attachment to the calculator which gives the calculator more capacity for memory storage. The acoustic coupler enables the calculator to be tied to computer by phone. The calculator first translates the teletypewriter data from its octal form into engineering units. At present, these units represent water stage, in feet, or cumulative rainfall, in feet. Second, the calculator sorts the data chronologically by station. Then it calculates daily rainfall, in inches, and prints the data in a format requested by the Corps of Engineers (Table I). The data are then scanned for errors. If the data appear correct, they are telecopied to the Corps of Engineers in Jacksonville and Clewiston, Florida. The time required for the transmission of data from the Everglades via the satellite, the NASA tracking stations, and the Geological Survey to the Corps of Engineers is less than 2 hours, a significant improvement over prior techniques requiring as much as 2 months. The National Park Service and the Fish and Wildlife Service receive a full table of data each Friday. The Central and Southern Florida Flood Control District at West Palm Beach receives data from the Corps of Engineers in Jacksonville.

After the data have been calculated, sorted, and sent to the users in the form shown in Table I, the data are stored on cassette tape. The data are condensed by eliminating all but daily readings and are stored in annual data files. After the data are loaded into the annual files, data from stations designated as key stations are fed into the plotter, which is on line to the programmable calculator. Figure 9 shows hydrographs compiled from data relayed from three DCPs in Conservation Area 1. Hydrographs are usually updated each month and mailed to the users. LANDSAT programs presently used on the calculator in Miami are:

- Reads teletypewriter tape and converts to gage heights or dial reading.
- Prints out weekly summary table of stage and rainfall.
- Stores midnight readings of stage and rainfall for each day.
- Prints daily calendar year plot.
- Prints daily water year plot of stage.

Additional programs for the programmable calculator are being written to analyze water-quality and additional meteorological data collected from LANDSAT-DCS stations now being installed.

LANDSAT MULTISPECTRAL SCANNER

LANDSAT imagery and DCS data acquired on Conservation Area 1 show a complementary application for these data.

Conservation Area 1. - Conservation Area 1 covers 221 square miles (572 square kilometers) and is contained within the Loxahatchee National Wildlife Refuge. As seen in the NASA image of Figure 10, the area is pear-shaped and bounded by levees. Just inside the levees are ditches or canals formed by the removal of soil for the levees. The canals expedite the movement of water into or out of the refuge.

The vegetation of this area (ref 15) is shown in Figure 11. The part of the Everglades (ref 16) consists of prairie-like flats that are covered with shallow water most of the year. Stands of sawgrass intersperse the flats. Shallow ponds and sloughs support white water-lilies and other acquatic plants that bloom throughout the year. The landscape is dotted with tree islands that vary in size from a fraction of an acre to several hundred acres. Wax myrtle, redbay, dahoon holly, and ferns on the islands retain their foliage throughout the year. Various air plants grow in profusion within its confines.

Fall and winter migrations result in spectacular bird concentrations. Flocks of herons, egrets, and ibises, often numbering in the thousands, congregate where receding water strands myriads of small fish and crayfish. The tree islands in winter are frequently alive with small birds, including several species that otherwise winter south of the United States. Among the more interesting resident species are limpkin, sandhill crane, wood duck, and mottled duck. Blue-winged teal and ring-necked ducks are the most abundant ducks during winter. Coots are year-round residents, but are abundant only in winter. The cattle egret, an emigrant from the Old World, is now common on the refuge and adjacent pasture lands.

A noticeable relation exists between water levels and the abundance of birds requiring an aquatic habitat. Thousands of colonial and water birds nest and roost on the refuge when sufficient water is available to provide the necessary environment.

LANDSAT Imagery. - Multispectral imagery of Florida is obtained every 18 days by LANDSAT from an altitude of approximately 560 miles (900 kilometers). These data are transmitted from the satellite to the NASA Goddard Space Flight Center or the Goldstone Tracking Station in digital format. The digital tapes are then mailed to the Miami office of the Geological Survey. Several systems were used to extract spectral information from these tapes in order to construct thematic maps. Electronic processing of the LANDSAT MSS data was accomplished using the computer facilities of the Bendix Aerospace Systems Division, NASA Kennedy Space Center Earth Resources Program Office, the General Electric Corporation, the Stanford Research Institute, and the IBM Corporation to produce different types of maps by computer.

Figure 12 shows radiance (or reflectance) maps of Conservation Area 1 derived from electronic processing of LANDSAT MSS band 7 data acquired on 14 February, 4 March, and 22 March of 1973.

For this illustration, the original LANDSAT radiance levels, which were enhanced and color-coded on film, are shown as gray-scale levels. The darker the gray-scale, the lower the radiance measurement, which infers water. The water depth in this area ranges from zero, as denoted by white, to about 2 feet (0.6 meter), denoted by black.

The change or loss in water stored in the area from February 14 to March 22 is readily observed by the changes in gray-scale of the enhanced images in Figure 12. The water stored in the area for a given time is obtained as illustrated in Figure 13, where the DCS (Figure 14) is used to provide quantative in situ data on the elevation of each water-depth category and MSS imagery is used to obtain the areal extent of each category. Surface area times elevation (depth) for each category yields directly the water volume retained by the area. Additionally, knowing the change in water storage and the surface inflow and outflow, it is possible to calculate the evapotranspiration and seepage, as illustrated in the model of Figure 15.

Between February 14 and March 22, of 1973, three successive sets of LANDSAT-MSS data were combined with existing ground-truth data and the DCS data for Conservation Area 1. During this period, the water levels were declining, as noted previously in the hydrograph of Figure 8, and the enhanced imagery of Figure 12. For February 14 through March 22, the evapotranspiration and seepage, surface water distribution, and storage for Conservation Area 1 were computed as shown in Figure 16. This trial run indicated that an operational water-management model for the Everglades is feasible.

SYSTEM DESCRIPTION

A system to satisfy the hydrologic data needs of water resources management is illustrated in Figure 17. This system would be configured to achieve the benefits available from the combined use of LANDSAT MSS imagery and in situ monitoring by DCS.

The DCS part (Figure 18) of the system is operational, however, the imagery part is not. One reason for this is the long delay (approximately 6 to 8 weeks after a LANDSAT pass) in obtaining LANDSAT imagery and computer tapes. The other reason is the difficulty of locating DCPs and other point sampling stations within the LANDSAT images and tapes. A computer technique (ref 17) has recently been developed that will permit the earth coordinates (latitude and longitude) of the sampling station to be called up and displayed on the LANDSAT scene (Figure 19).

LANDSAT MSS images provide data on scene radiance, and changes in scene radiance corresponding to water "color" (reflectances) and changes that may be a result of parameters that include depth, turbidity, chlorophylls, algal population, particulate carbon among others, In situ measurements, by field teams or a DCP are essential to quantify the LANDSAT image response. LANDSAT imagery used as an adjunct to the point-sampling provides an economical basis for extrapolating water parameters from the point samples to unsampled areas, and provides a synoptic view of water mass boundaries that no amount of ground sampling or monitoring can provide.

The water budget example developed for Conservation Area 1 uses water stage from DCPs with water surface area from imagery to obtain water stage-volume relations. Figure 20 shows a color-enhanced image of southern Florida in LANDSAT band 7. As in the case of Conservation Area 1, water stage is associated with scene radiance as denoted by color but must be quantified by in situ measurements within each color category. The synoptic view by LANDSAT and computer processing (refs. 17 and 18) rapidly provides surface area and volume relations.

In addition to using LANDSAT imagery to extrapolate from DCP measurements, LANDSAT imagery is also useful for optimizing the deployment of DCPs and field teams. As noted, LANDSAT responds to radiance and differences in scene radiance. Analysis of this imagery may show that two DCPs are occupying a water body of similar radiance. On the other hand, the imagery may show areas in which a significant change has occurred and in which a DCP should, perhaps, be positioned to quantify change. For example, LANDSAT imagery may be used to monitor a basin wherein mining is occurring. A change in radiance of a water body in the area may be very significant. A field team may be deployed to point sample and to set up a DCP to quantify reasons for change.

The LANDSAT MSS data also provide an economical base for computerized mapping of land use about DCPs providing water quality indicators, i.e., dissolved oxygen, conductivity, turbidity, etc. Ready access of land use information about these DCPs will permit cause-effect studies which will result in a better understanding of factors causing changes in water quality.

SUMMARY

The usefulness of LANDSAT to improving the overall effectiveness of collecting and disseminating hydrologic data was evaluated. LANDSAT MSS imagery and in situ monitoring by LANDSAT-DCS were used to evaluate their separate and combined capabilities.

Twenty data collection platforms were established in southern Florida. Water level and rainfall measurements were collected and disseminated to users in less than 2 hours, a significant improvement over conventional techniques requiring up to 2 months. The improved network performance is having a significant and beneficial impact on the development of water budgets and the water distribution to the people, fauna, and flora of southern Florida.

LANDSAT imagery was found to significantly enhance the utility of ground measurements. Water stage is correlated with water surface areas from imagery in order to obtain water stage-volume relations. As an adjunct to the point sampling, the imagery provides an economical basis for extrapolating water parameters from the point samples to unsampled data and provides a synoptic view of water mass boundaries that no amount of ground sampling or monitoring could provide. Additional hardware and software developments are needed to fully achieve the benefits available in the combined use of DCS and MSS data.

The DCS system is now an operational element in the hydrologic data network in south Florida. Water-stage and rainfall from ground stations are transmitted from the Everglades via LANDSAT, the NASA tracking stations, and the Geological Survey, to the Corps of Engineers. Other users receiving water resource data from this network include Central and Southern Florida Flood Control District, the National Park Service, and the U.S. Fish and Wildlife Service.

The importance of the space-relayed data can also be shown by a comparison of the accuracy and frequency of data received through the Miami Geological Survey teletypewriter with data from the existing remote radio transmission systems in southern Florida. Even though these microwave systems transmit "line-of-sight" from tower to tower, the frequent meteorologic disturbances in south Florida prevent the reliable transmissions of accurate synoptic information on rainfall and water stage that is essential in managing water resources. LANDSAT on the other hand, has been providing the Geological Survey with five transmissions of these parameters per day and an opportunity to service faulty platform recorders within 24 hours. This enhances the opportunity for a constant flow of information and makes it possible for the U.S. Corps of Engineers and the Central and Southern Florida Flood Control District to make daily decisions in managing and controlling the water resources.

The DCS System also makes it possible to develop strategies for efficient field manpower deployment. For example, with DCS, manpower can be deployed to malfunctioning stations or to stations that are recording extraordinary hydrologic conditions where supplementary manual measurements are highly desirable. The emphasis can be shifted to sending personnel where they are most needed, instead of the routine station-servicing trips. This improves the manpower efficiency, decreases the down-time of hydrologic instruments and data loss, and frees manpower for new high-priority activities. Also, data from the network can be made available in near-real time to meet the growing data needs of water-resource management agencies.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the many contributions to this investigation supplied by:

- The NASA Kennedy Space Center Earth Application Office (for use of their digital-optical system for processing LANDSAT imagery).
- The Bendix Aerospace Systems Division; Larry E. Reed, N.J. Shah, and C. L. Wilson (for use of electronic data processing equipment and techniques).
- The U.S. Corps of Engineers, the U.S. Department of the Interior, Fish and Wildlife Service, and the U.S. National Park Service (for their support of the DCS Program).

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16. US Dept of Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife; Paper RL-175-R-3; Birds of the Loxahatchee National Wildlife Refuge; Revised March 1967.

17. R.H. Rogers, L. Reed, N.J. Shah, and V.E. Smith; "Computer Mapping of Turbidity and Circulation Patterns in Saginaw Bay, Michigan (Lake Huron) from ERTS Data"; Proceedings of ASP-ACSM Convention at Washington, DC.; March 1975.

18. R.H. Rogers, L.E. Reed, N.J. Shah; "Automatic Classification of Eutrophication of Inland Lakes from Spacecraft Data"; Proceedings of the Ninth International Symposium on Remote Sensing of Environment; Vol. II; April 1974.

Table I

TYPICAL WATER LEVEL AND RAINFALL REPORT TELECOPIED TO DATA USERS

USGS MIAMI, FLA.
DATA FROM LANDSAT SATELLITE
WATER SURFACE ELEVATION FT MEAN SEA LEVEL

DATE DAY TIME	32 FRI 2343	33 SAT 3248	34 SUN 2354	35 MON 2359	36 TUE 2221	37 WED 2227	38 THRU 2355
128	16.62	16.61	16.61	16.59	16.56	16.53	16.52
141	16.48	16.47	16.49	16.46	16.44	16.43	16.42
142	16.44	16.42	16.42	16.41	16.39	16.37	16.35
111	12.36	12.34	12.33	12.30	12.27	12.26	12.23
112	12.10	12.07	12.05	12.02	12.00	11.98	11.97
62	9.42	9.38	9.38	9.36	9.31	9.26	9.21
63	8.67	8.64	8.64	8.61	8.58	8.56	8.54
64	8.47	8.46	8.46	8.44	8.43	8.42	8.41
65	8.41	8.40	8.39	8.38	8.37	8.36	8.35
5	5.67	5.66	5.65	6.64	5.62	5.62	5.61
15	2.77	2.76	2.75	2.74	2.73	2.72	2.71
105	6.71	6.67	6.65	6.61	6.57	6.54	6.50

RAINFALL IN INCHES

128	0.00	0.00	0.00	0.00	0.00	0.00	0.00
141	0.00	0.00	0.25	0.00	0.00	0.00	0.00
142	0.00	0.00	0.00	0.06	0.00	0.00	0.00
111	0.00	0.00	0.19	0.00	0.00	0.00	0.00
112	0.00	0.00	0.06	0.00	0.00	0.00	0.00
62	0.00	0.00	0.06	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: Readings will be revised as later data are received

314

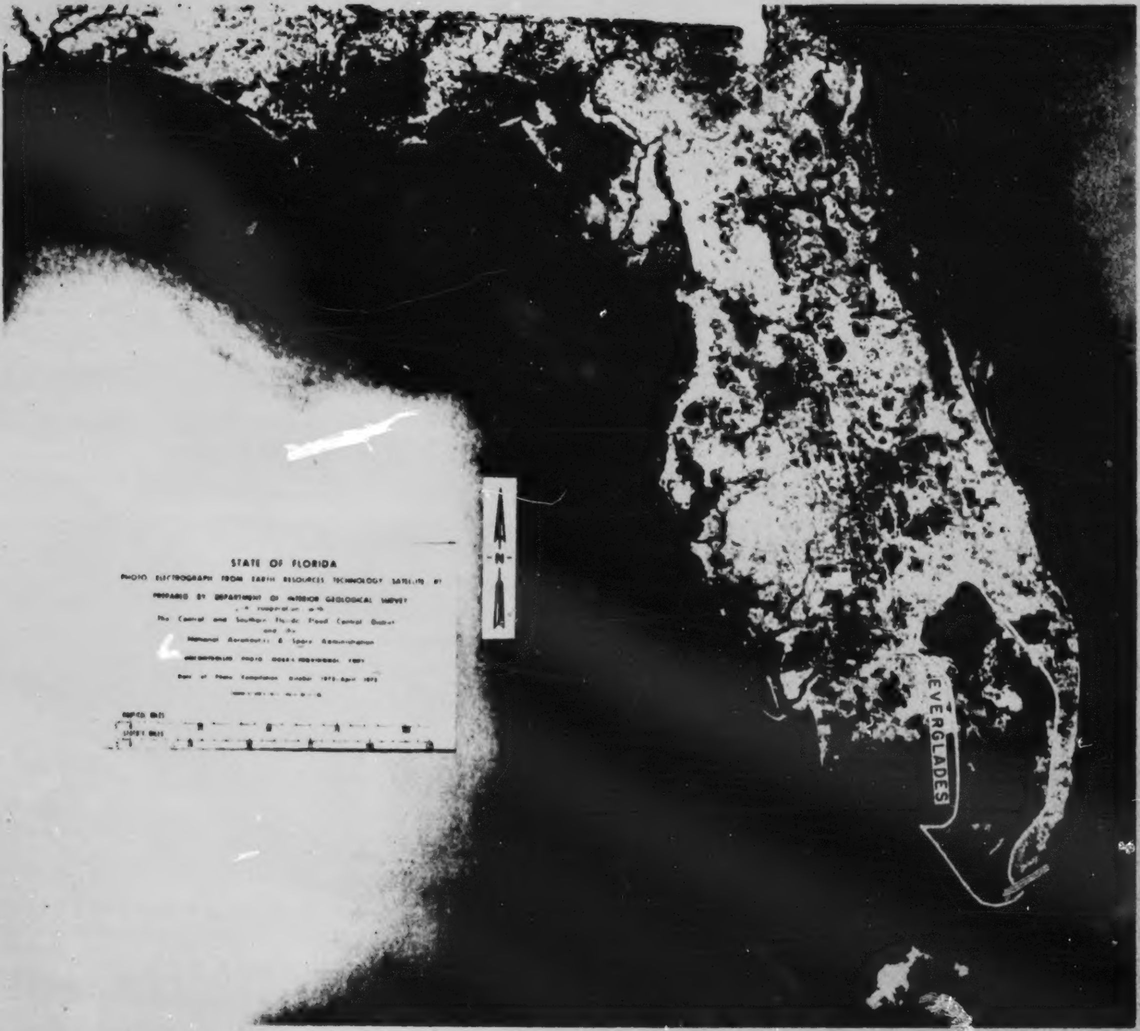

STATE OF FLORIDA
N
EVERGLADES

Figure 1. Photo mosaic of Florida, compiled from 16 LANDSAT images between October 1972-April 1973 of band 7 of the multispectral scanner. The delineated area is the Everglades.

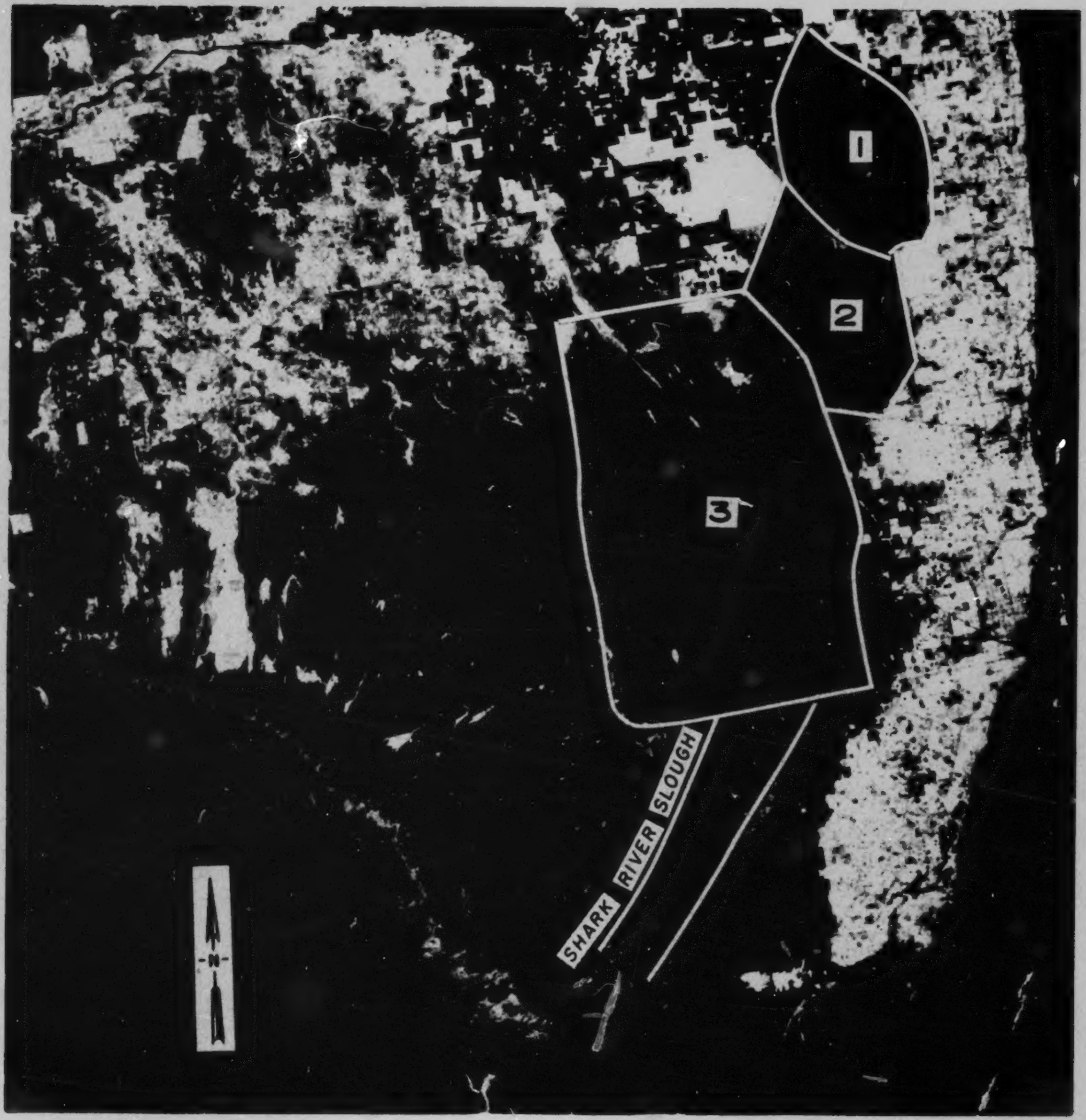

1
2
3
SHARK RIVER SLOUGH
N

Figure 2. A LANDSAT Multispectral Image, Band 7, March 22, 1973, NASA, E-1242-15240, of South Florida. The areas outlined are: Conservation Areas 1, 2 and 3 and Shark River Slough. Lake Okeechobee can be seen at top of photo.

316

WATER BUDGET = INFLOW + RAINFALL
-EVAPORATION-TRANSPIRATION-SEEPAGE-OUTFLOW

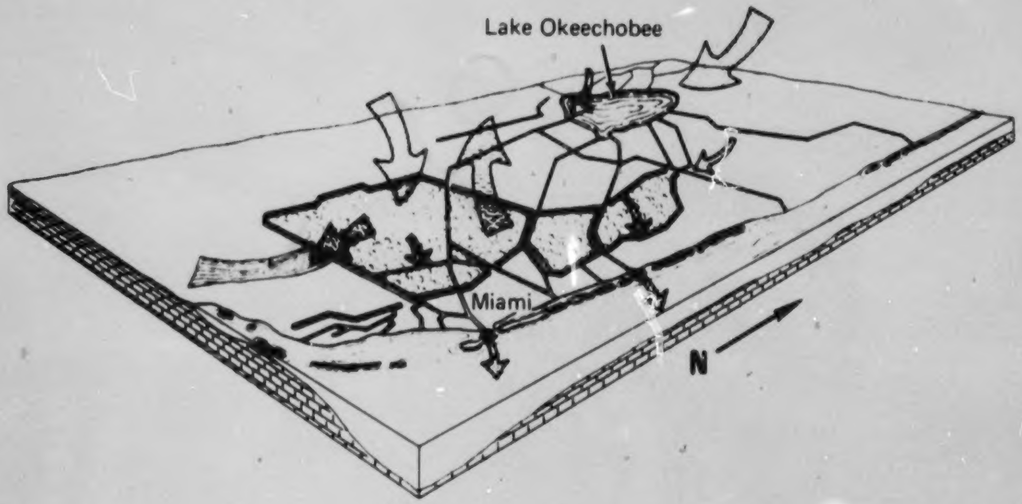

Lake Okeechobee
Miami
N

Figure 3. Schematic diagram of a water budget for the Everglades, southeast Florida.

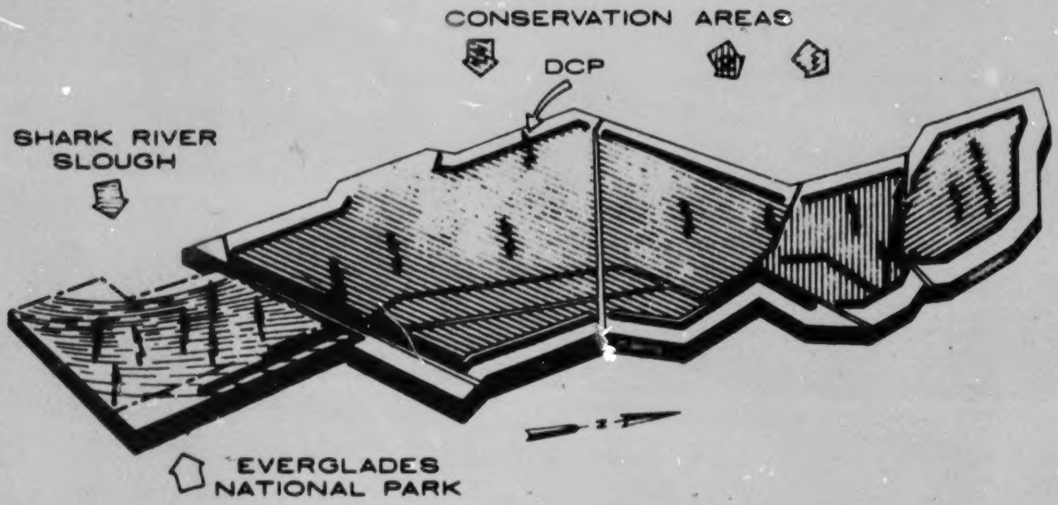

CONSERVATION AREAS
DCP
SHARK RIVER SLOUGH
EVERGLADES NATIONAL PARK

Figure 4. Schematic diagram of the Everglades basin, showing relative locations of the data collection platforms within the three conservation areas and the Shark River Slough.

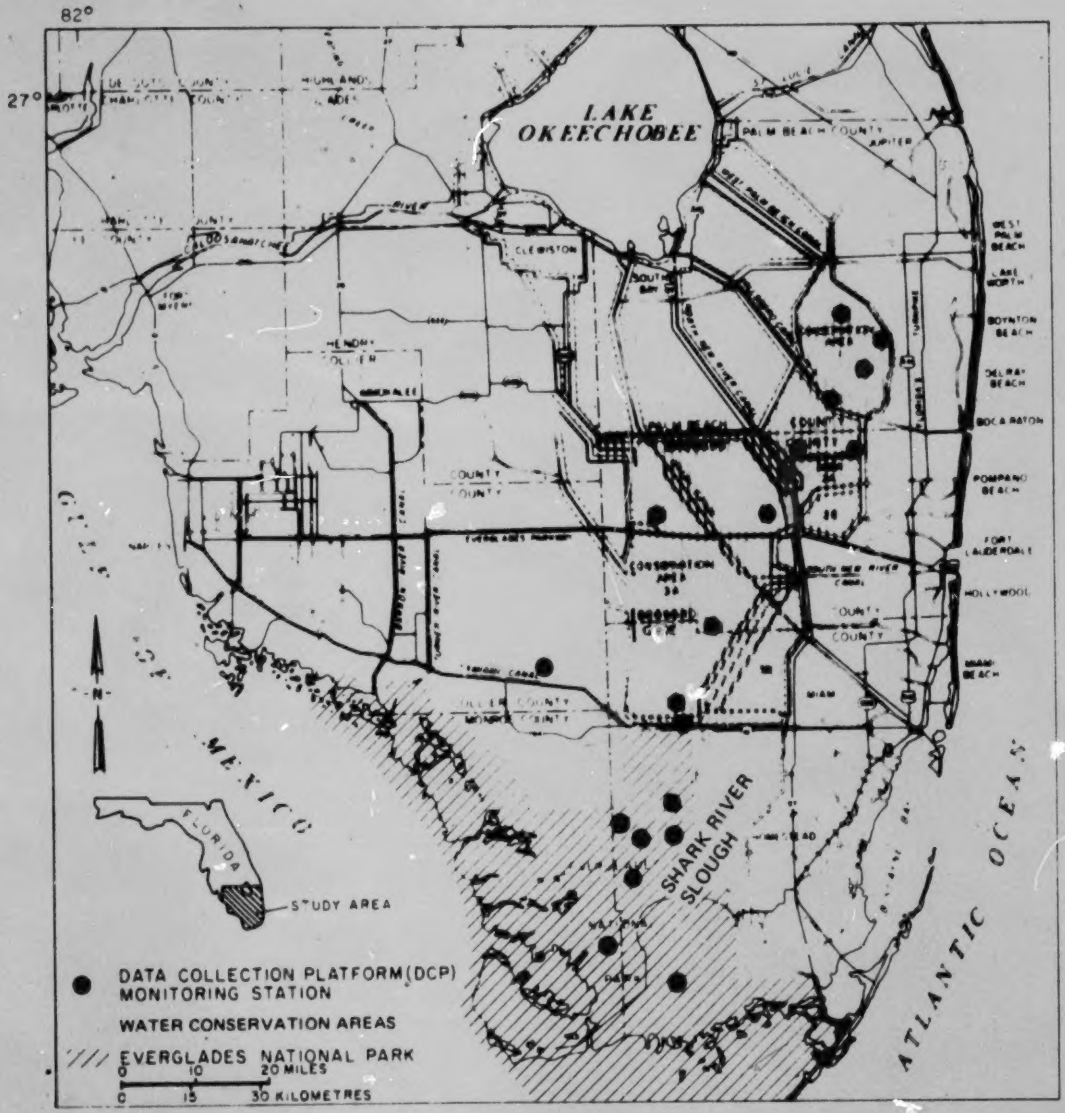

82°
27°
LAKE OKEECHOBEE
PALM BEACH COUNTY
CLEWISTON
WEST PALM BEACH
LAKE WORTH
BOYNTON BEACH
DELRAY BEACH
BOCA RATON
POMPANO BEACH
FORT LAUDERDALE
HOLLYWOOD
MIAMI BEACH
GULF OF MEXICO
SHARK RIVER SLOUGH
ATLANTIC OCEAN
N
FLORIDA
STUDY AREA
DATA COLLECTION PLATFORM(DCP) MONITORING STATION
WATER CONSERVATION AREAS
EVERGLADES NATIONAL PARK
0 10 20 MILES
0 15 30 KILOMETRES

Figure 5. Locations of conservation areas and DCP monitoring stations.

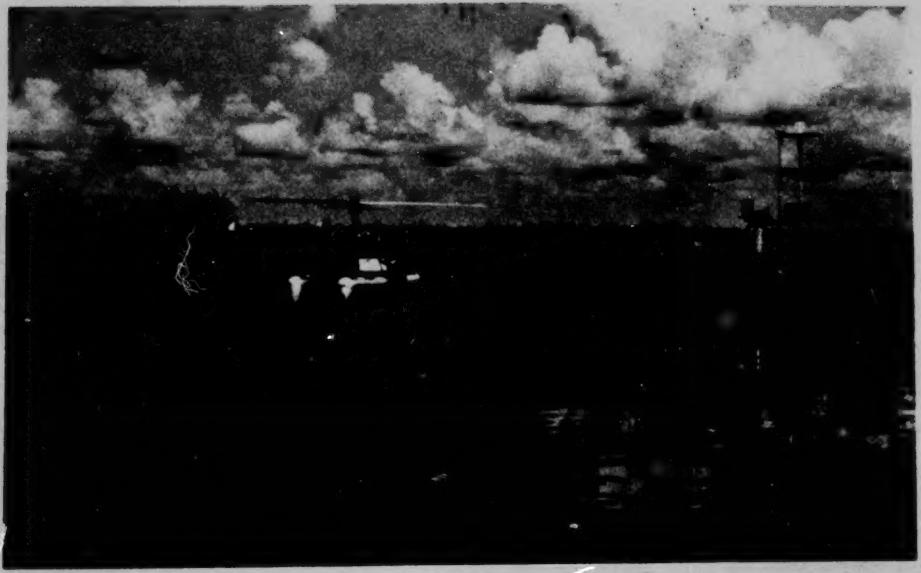


Figure 6. Data collection platform in Conservation Area 1. These stations collect and transmit water-level and rainfall data for relay by LANDSAT.

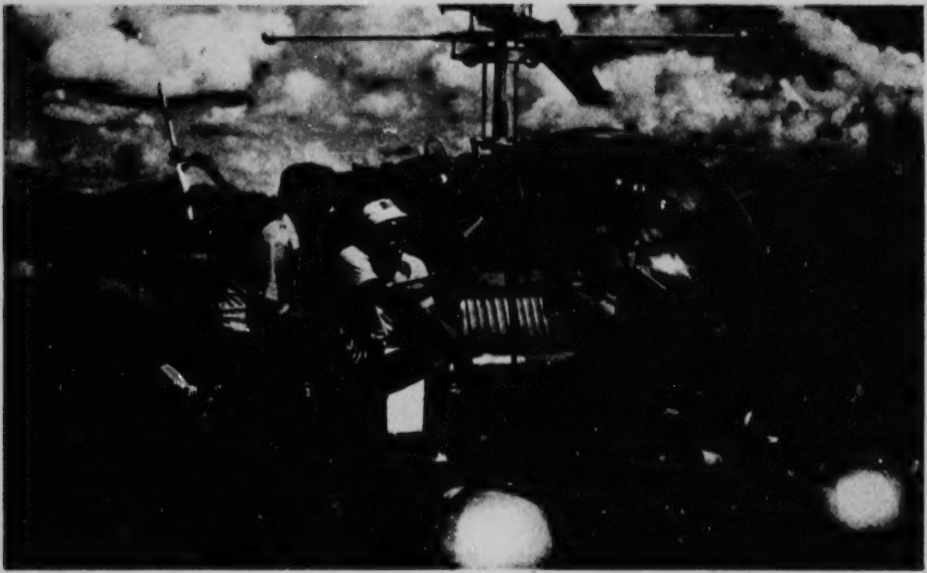


Figure 7. Team collecting ground truth data such as plant community identification and soil characteristics in Conservation Area 1.

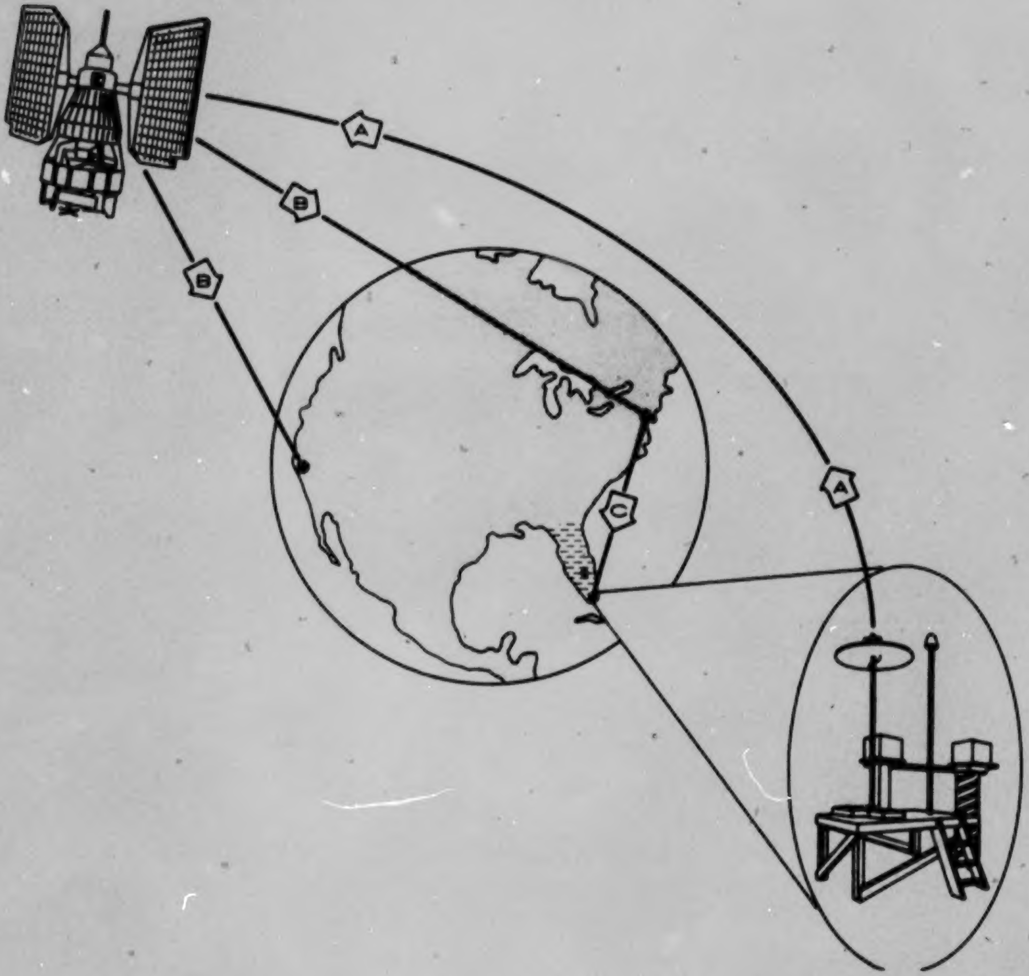


Figure 8. Data are transmitted from the data collection platforms in the Everglades (A) via LANDSAT to NASA tracking stations at Goldstone, Calif., and GSFC, Greenbelt, Md. (B). The data are then transmitted, via NASA communications network, to the Geological Survey office in Miami.

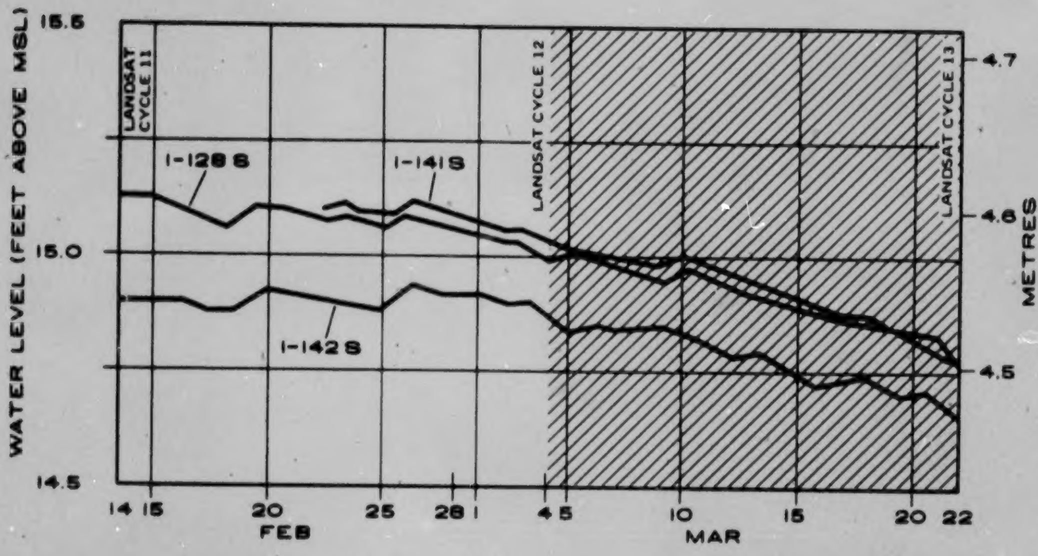


Figure 9. Hydrographs compiled from daily recordings from three **DCPs in Conservation** Area 1, February 14 - March 22, 1973. During this period LANDSAT MSS imagery was collected for the three LANDSAT overflights noted as cycles 11, 12, 13.

323

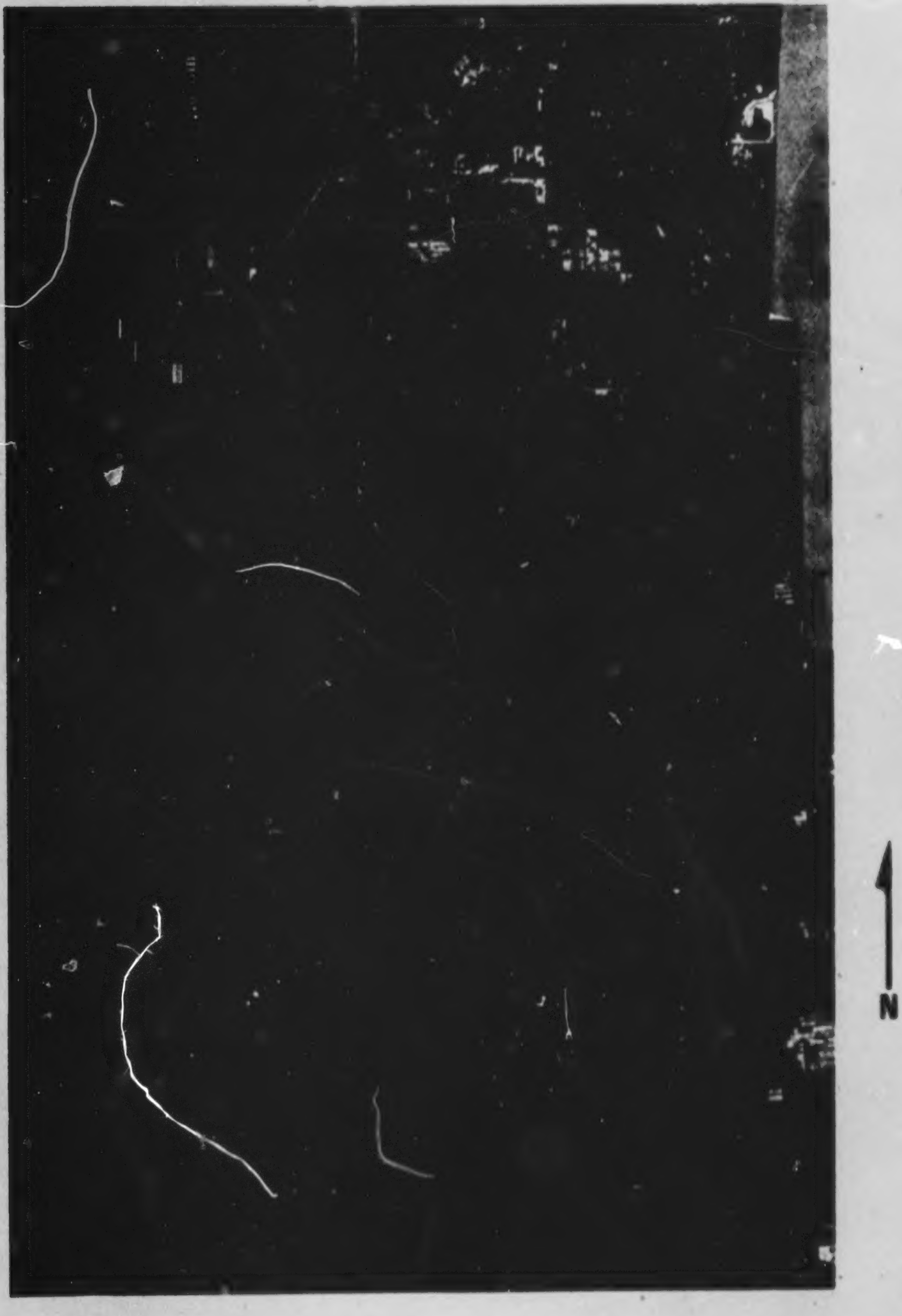


Figure 10. NASA U-2 Photomosaic of Conservation Area 1 January 1973.

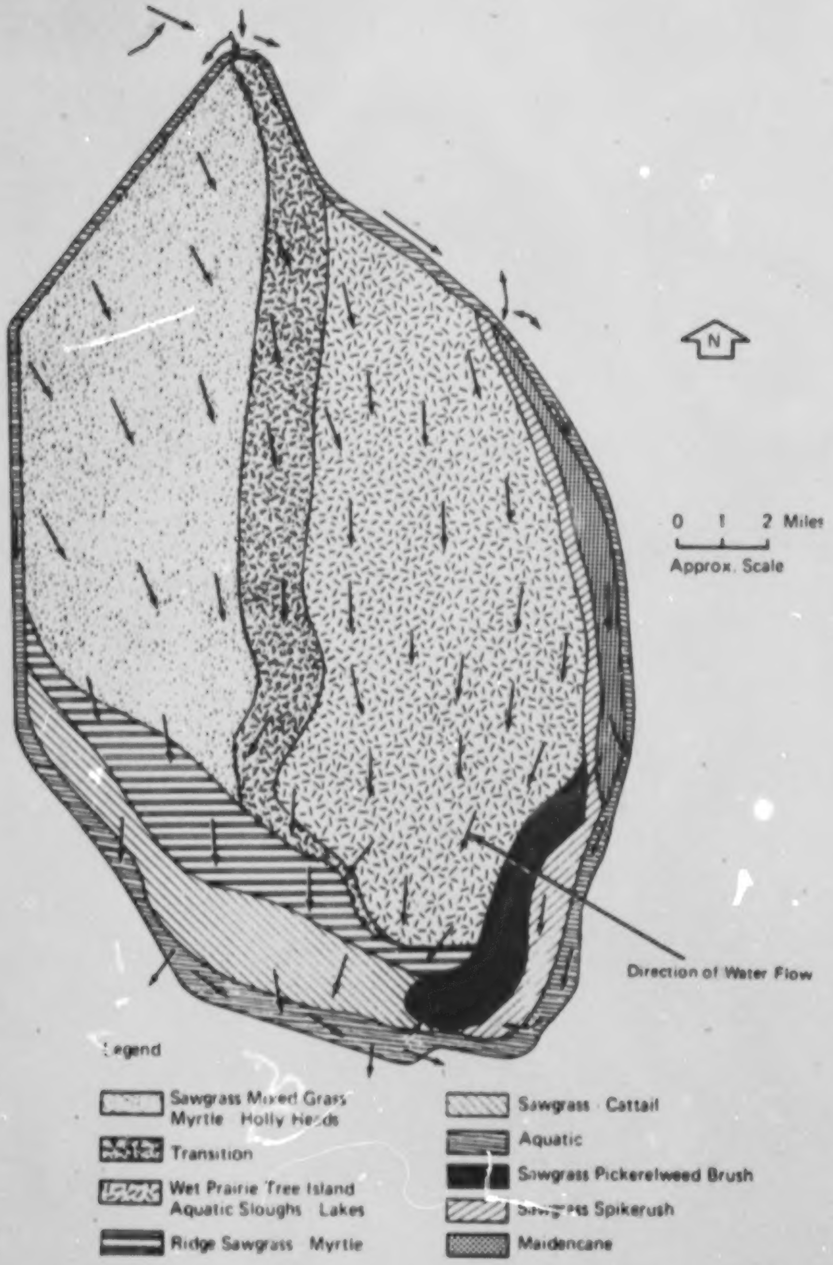
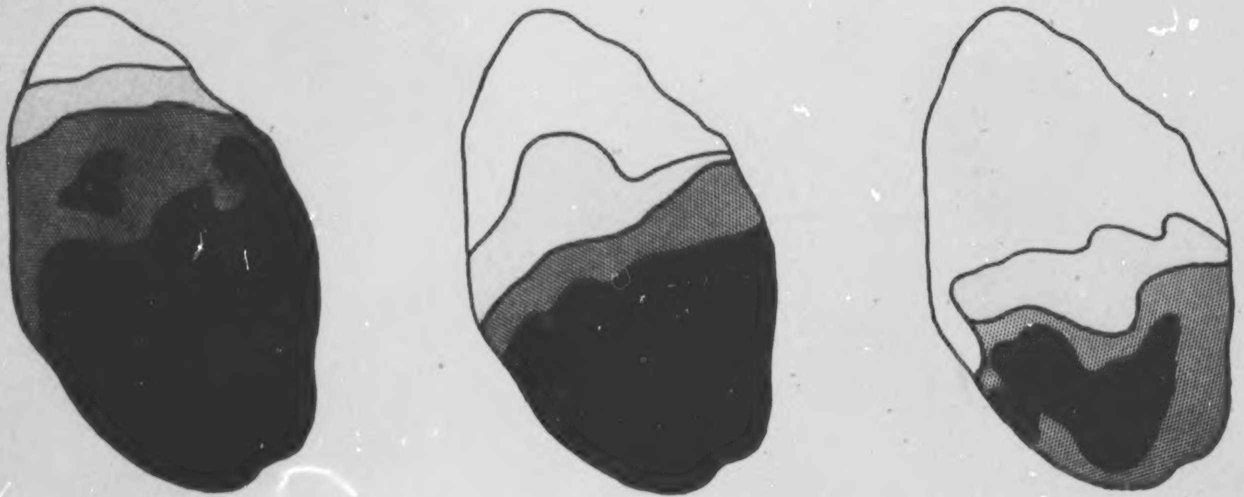

N
0 1 2 Miles
Approx. Scale
Direction of Water Flow
Legend
Sawgrass Mixed Grass Myrtle Holly Heads
Transition
Wet Prairie Tree Island Aquatic Sloughs Lakes
Ridge Sawgrass Myrtle
Sawgrass Cattail
Aquatic
Sawgrass Pickerelweed Brush
Sawgrass Spikerush
Maidencane

Figure 11. Vegetation zones of Conservation Area 1 as determined by U.S. Department of Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife.



February 14, 1973

March 4, 1973

March 22, 1973

Figure 12. Radiance (reflectance) map, of the Loxahatchee Wildlife Refuge (Conservation Area 1) produced from enhanced LANDSAT band 7 imagery. Darker map tones correspond to lower radiance (reflectance) and deeper water. Black is deepest **(0.6 meters)** and white is dry land.

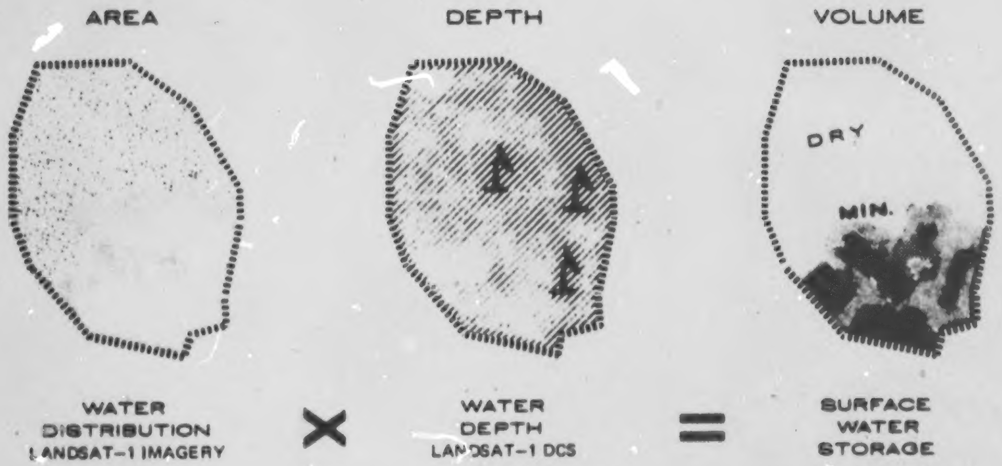
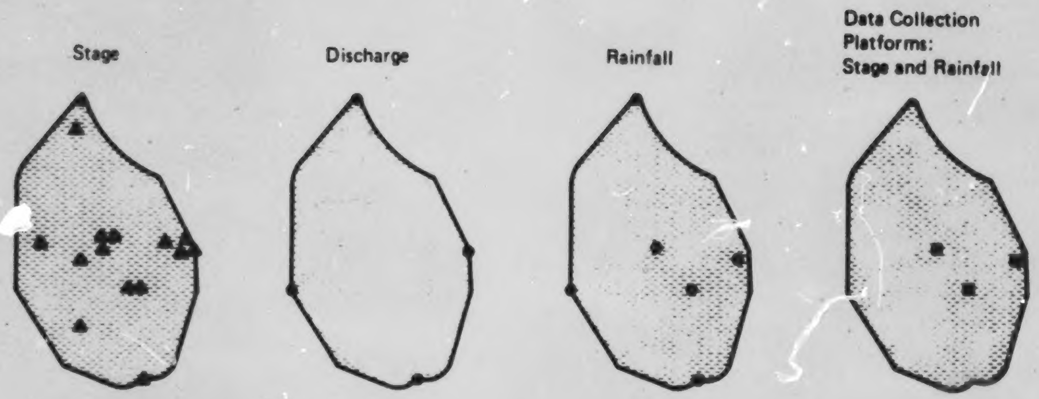

AREA
DEPTH
VOLUME
DRY
MIN.
WATER DISTRIBUTION LANDSAT-1 IMAGERY
×
WATER DEPTH LANDSAT-1 DCS
=
SURFACE WATER STORAGE

Figure 13. Schematic of use of space-relayed data to calculate surface-water storage. LANDSAT data of three successive passes on February 14, March 4, and March 23, 1973, of Conservation Area 1 were used to demonstrate feasibility of this method of determining surface-water storage.



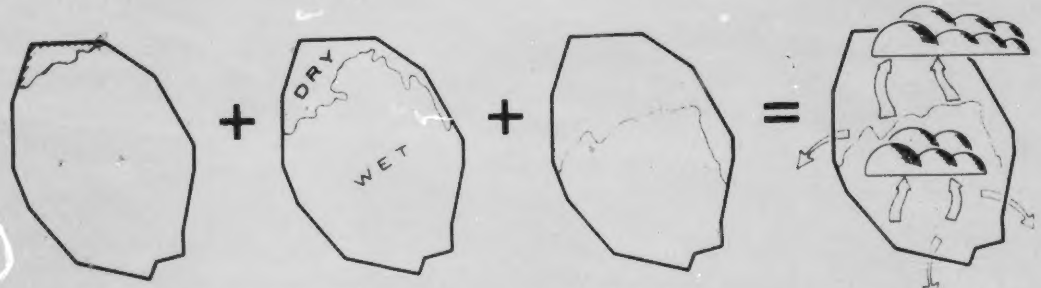
Stage

Discharge

Rainfall

Data Collection Platforms: Stage and Rainfall

Figure 14. Location of ground truth station used in the evaluation of the February 14, March 4, and March 22, 1973, MSS data for Conservation Area 1.



FEB 14, 1973 MAR 4, 1973 MAR 22, 1973 NET CHANGE, SURFACE WATER DISTRIBUTION

Figure 15. Schematic of use of space-relayed data to calculate evapotranspiration and seepage. LANDSAT data of three successive passes on February 14, March 4, and March 22, 1973, of Conservation Area 1 were used to demonstrate feasibility of determining evapotranspiration and seepage.

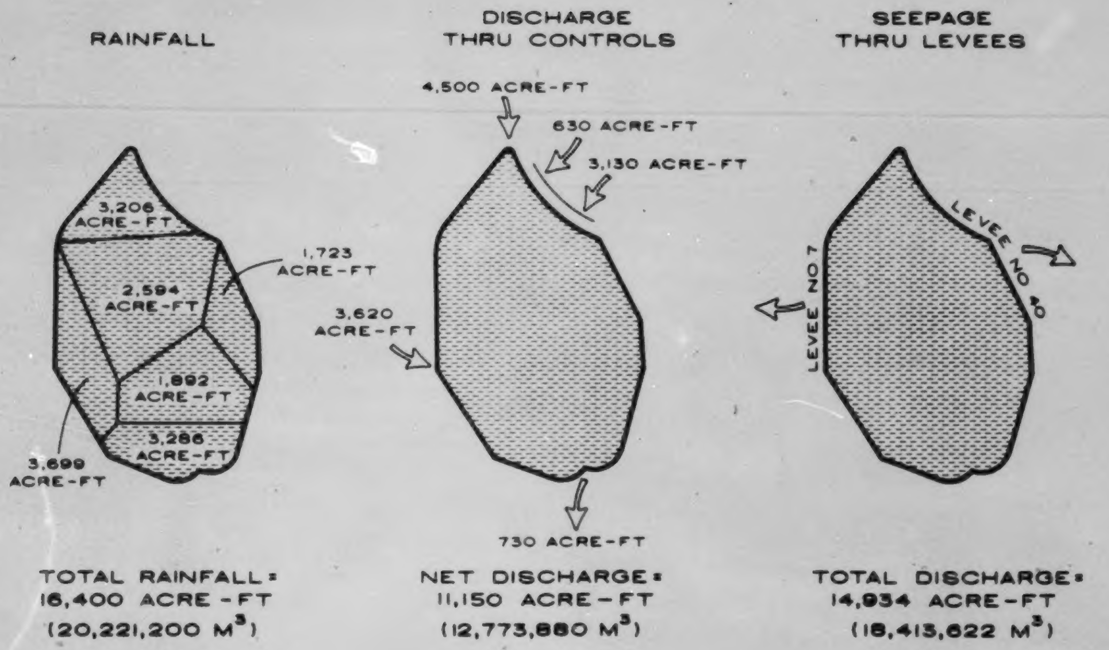

RAINFALL
DISCHARGE THRU CONTROLS
SEEPAGE THRU LEVEES
3,206 ACRE-FT
1,723 ACRE-FT
2,594 ACRE-FT
1,892 ACRE-FT
3,286 ACRE-FT
3,699 ACRE-FT
4,500 ACRE-FT
630 ACRE-FT
3,130 ACRE-FT
3,620 ACRE-FT
730 ACRE-FT
LEVEE NO 7
LEVEE NO 40
TOTAL RAINFALL = 16,400 ACRE-FT (20,221,200 M³)
NET DISCHARGE = 11,150 ACRE-FT (12,773,880 M³)
TOTAL DISCHARGE = 14,934 ACRE-FT (18,413,622 M³)

Figure 16. Hydrologic measurements compiled for interpreting MSS data for February 14, March 22, 1973 in Conservation Area 1. Source of Data: U.S. Corps of Engineers, oral communication.

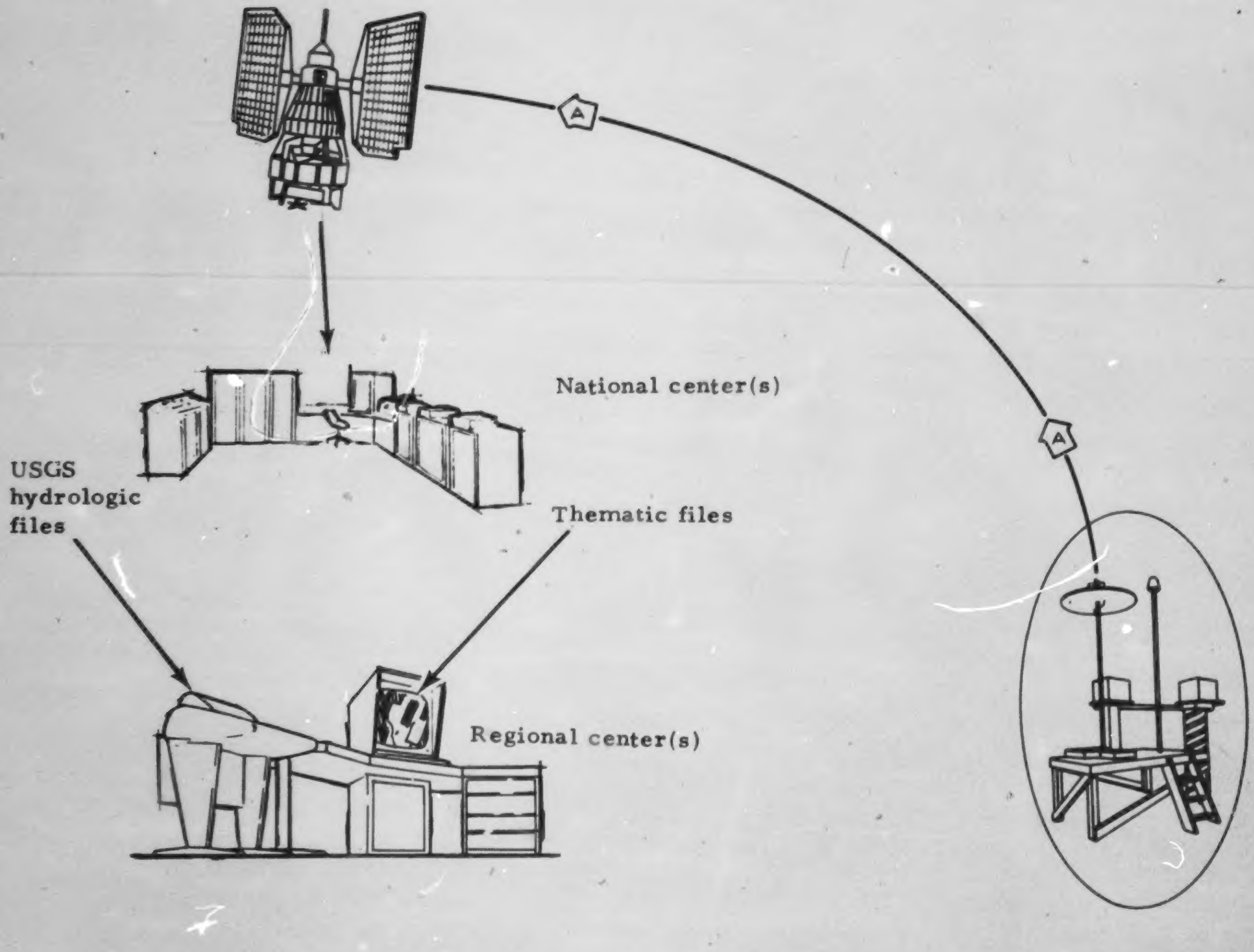

A
A
National center(s)
USGS hydrologic files
Thematic files
Regional center(s)

Figure 17. Concept of water management system operation.

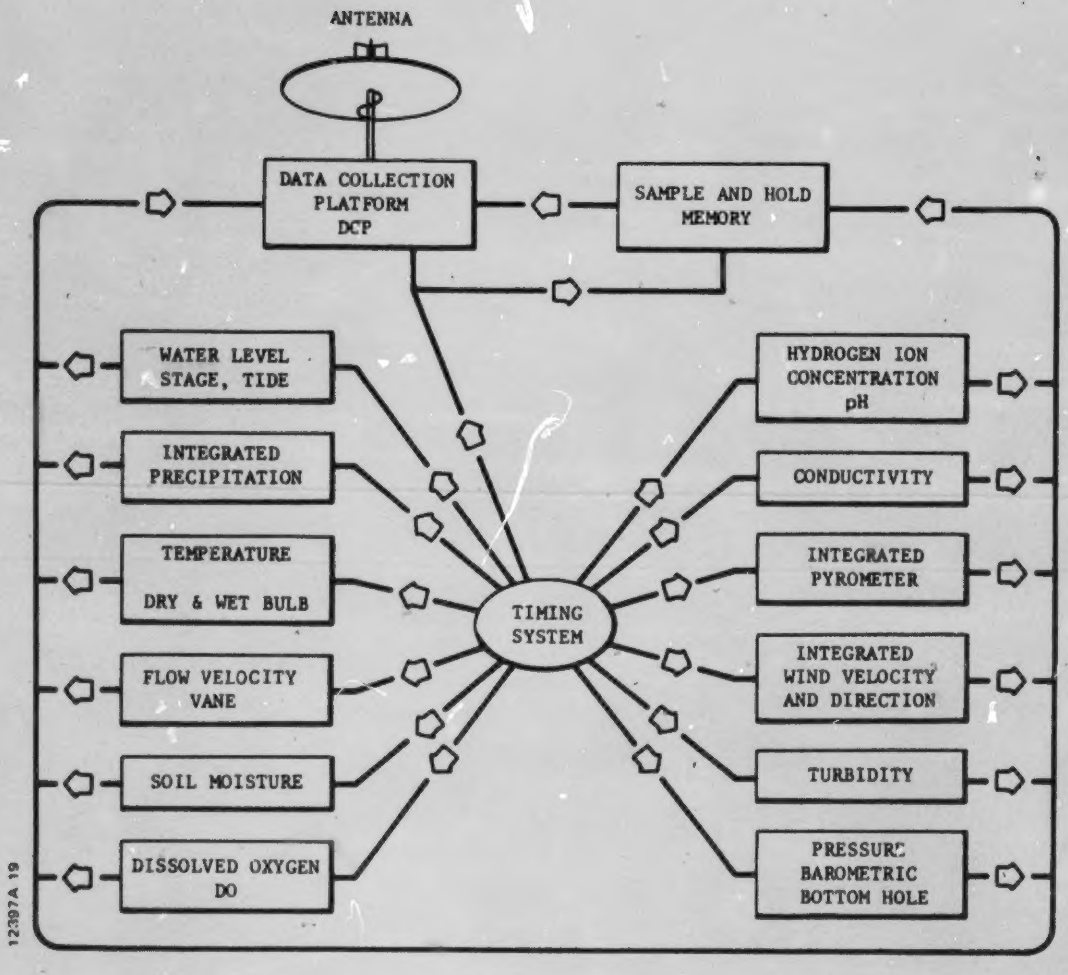

ANTENNA
DATA COLLECTION PLATFORM DCP
SAMPLE AND HOLD MEMORY
WATER LEVEL STAGE, TIDE
INTEGRATED PRECIPITATION
TEMPERATURE DRY & WET BULB
FLOW VELOCITY VANE
SOIL MOISTURE
DISSOLVED OXYGEN DO
TIMING SYSTEM
HYDROGEN ION CONCENTRATION pH
CONDUCTIVITY
INTEGRATED PYROMETER
INTEGRATED WIND VELOCITY AND DIRECTION
TURBIDITY
PRESSURE BAROMETRIC BOTTOM HOLE
12397A 19

Figure 18. Schematic of proposed system of parameters that are being connected to data collection platforms in water management areas in Florida. The sample and hold memory system developed by the Geological Survey will allow a daily collection of between 18 and 24 hours of data on the needed parameters to complete a water quality and quantity budget.

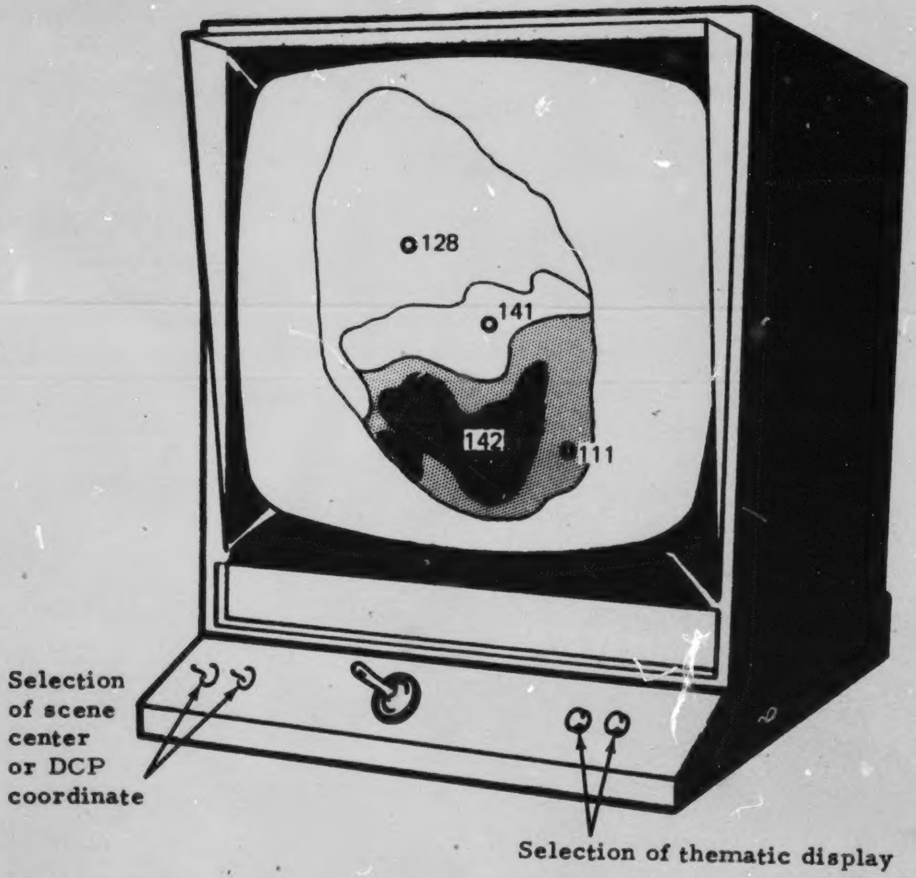

128
141
142
111
Selection of scene center or DCP coordinate
Selection of thematic display

Figure 19. Simulated TV display of LANDSAT MSS data with annotated location map of DCP's. Display inputs include latitude and longitude of scene center and theme (land-water categories).

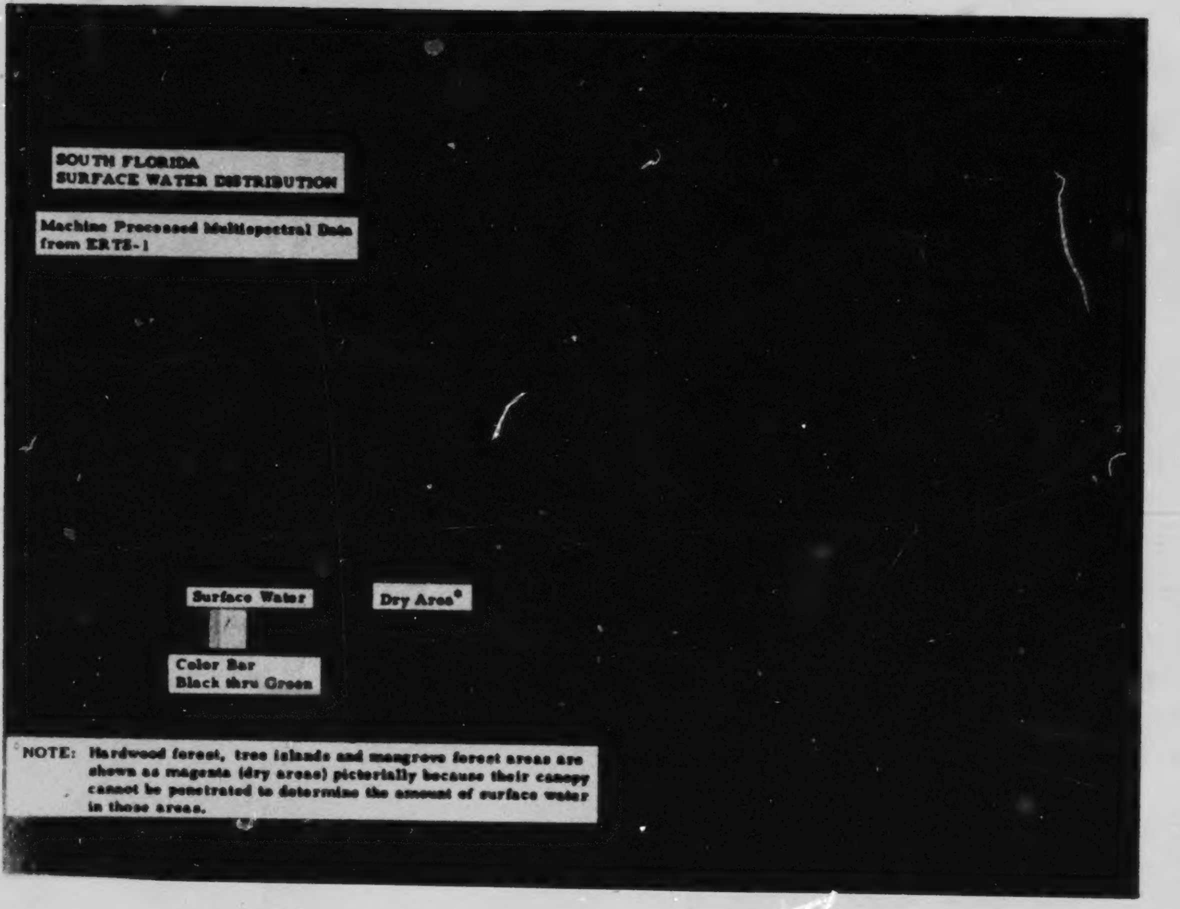

SOUTH FLORIDA
SURFACE WATER DISTRIBUTION
Machine Processed Multispectral Data from ERTS-1
Surface Water
Dry Area*
Color Bar
Black thru Green
*NOTE: Hardwood forest, tree islands and mangrove forest areas are shown as magenta (dry areas) pictorially because their canopy cannot be penetrated to determine the amount of surface water in those areas.

Figure 20. Color-enhanced LANDSAT image of south Florida. LANDSAT scene E-1242-15240, March 22, 1973. Yellow through black shades represent water of increasing depth, yellow indicating the shallowest water, black the deepest.

WATER MANAGEMENT

Vocabulary - Define the following terms in detail.

- Flora
- Fauna
- Evapotranspiration
- Water budget
- Kilometer
- Seepage
- Rainfall
- Slough
- Hydrologic
- Transpiration
- Outflow

Questions - Answer the following inquiries in detail.

1. What were objectives of this research project?
2. Why is a water management model important to the residents of south Florida?
3. What is the correlation between wood stork rookeries and water deficiencies?
4. Why is the Everglades called the "River of Grass"?
5. Explain the importance of data collection platforms?
6. What are the parameters of data collection platforms?
7. Explain the data transmission system?

Discussion Topics

1. Why is continual water movement essential to the Everglades?
2. What has the Corps of Engineers accomplished by extensive channelization?

COASTAL PROCESSES

High-altitude aerial photographs aid in investigations.

Principal Investigators
PROF. ROBERT DOLAN[1] University of Virginia
LINWOOD VINCENT University of Virginia

Photogrammetric Engineering, March 1973
Vol. 39 No. 3

ABSTRACT

Along sandy coasts the configuration of the shoreline is seldom straight, but rather CRESCENTIC in plain view. Crescentic forms can serve as indicators of beach and inshore bar-trough relationships, as well as places along the coast where surge and overwash may focus during storms. The increased availability of high-altitude aerial photographs offers, for the first time, a data source for the investigation of crescentic features of sandy coasts.

INTRODUCTION

The increased availability of high-altitude aerial photographs provide an excellent opportunity for the coastal investigator to monitor changes in shoreline features at scales that were previously only occasionally used. If combined with the low-altitude photographs and ground surveillance, high-altitude IMAGERY provides a valuable tool for engineering design and resource planning, as well as for studies of beach processes.[2] This paper considers a specific application - the measurement of crescentic shoreline features.

Shorelines have long been considered by GEOMORPHOLOGISTS and engineers in terms of straight lines, or along rocky coasts, forms which eventually develop into straight lines. Erosion clearly leads to straighter shorelines; however, sufficient data have now accumulated from aerial photographic studies to indicate that sand beaches are seldom straight, but consist of sinuous curves, with spits and bars protruding out into the inshore zone.[3] The CRESCENTIC forms have acquired the descriptive names sand waves and shoreline rhythms (Bruun, 1954; Hom-ma and Sonu, 1962; Bakker, 1968; Sonu and Russell, 1966; Dolan and Ferm, 1968; Zenkovich, 1967; Dolan, 1971; Komar, 1971; and Sonu, 1972) and generally occur as fields of en echelon points and embayments (Figure 1). The seaward projections and landward embayments are subaerial manifestations of transverse bars-and-troughs. The crescentic configuration, coupled with the uniform sizes and dynamics of the sand waves, confirms that sandy coastlines respond to a system of interrelated processes, and are not always randomly distributed irregularities which depend on local conditions. Therefore, it is essential to have a data source, such as high-altitude photographs, which provides a regional integrated view of these complex systems.

Crescentic coastal landforms are of more than academic importance. Many of the MORPHOLOGIC and SEDIMENTOLOGIC characteristics of sand beaches are associated directly with the rhythmic configuration. Research near Cape Hatteras, North Carolina, shows that the width, slope, and even the sediment size of the beach all vary in relation to positions within individual crescentic forms. This relationship explains much of the hitherto unexplained variance that investigators have found in correlation between wave action, as measured offshore, and beach characteristics.

Submarine bars associated with the sand waves have deep-water channels immediately offshore from embayments. Depressions in the bars allow higher waves to penetrate closer inshore, breaking on the beach face rather than on the bar. These channels and the offshore bar system can be seen on aerial photographs by comparing the shoaling of the incoming breakers with the sand wave field (Figure 2). Thus, the focus of destructive storm surge and overwash along barrier islands is related to the field position rather than by chance variation in the submarine bars or low places in the barrier dunes (Dolan, 1971).

THE PHOTOGRAPHS

Several sets of high-altitude photographs have been taken of the middle Atlantic coastal region. Five sets are now available of the Cape Hatteras area since 1968, and most of the barrier islands of Virginia and North Carolina are scheduled to be photographed by U-2 aircraft every 18 days under the NASA-USGS CARETS program. Commencing in 1972, space imagery of ERTS-1 will provide regular coverage of the mid-Atlantic coast.

Although the types of imagery available to secondary users depend on the agency and the objectives of the original NASA- and USGS-funded projects, color-infrared is available from most of the NASA-USGS aircraft missions.[4] The high-altitude photographs are taken by reconnaissance aircraft, RB-57's and U-2's. Although the aircraft program is presently considered experimental, it is expected to continue in a complementary role to the ERTS and Skylab satellite platforms. The scales most frequently requested by investigators are 1:60,000 and 1:120,000.

On photographs at a scale of 1:60,000, one inch represents slightly less than one mile, or approximately the scale of standard USGS quadrangle maps. At a scale of 1:120,000, one inch represents two miles, so the standard 9 x 9-inch negative covers an area of 324 square miles (18 by 18 miles) as compared to 81 square miles for 1:60,000. The same area with lower-altitude photographs (1:20,000) would require 36 9 x 9 inch negatives.

The quality photographic films used in the NASA high-altitude photographs provide amazing degrees of resolution. Magnification in excess of 10X can be used for detailed measurements. The range of measurement possible on the photography is well within the error, due to distortion, inherent in the photograph.

THE ANALYSIS

Sequential measurements of the rhythmic features in the Cape Hatteras and Cape Lookout National Seashore areas indicate the following attributes. (1) Sand wave lengths range from 150 to 1000 meters, with most between 500 and 600 meters. (2) Wave amplitudes average about 15 to 25 meters and may reach amplitudes of 40 meters. (3) Although the question of movement of the sand wave field along the beach is still under investigation, the rate of change is clearly a function of wave energy, and thus greatest during the stormy winter season along the mid-Atlantic.

Crescentic coastal landforms, as described by their wave lengths and amplitudes, occur throughout the world. Their dimensional range also seems to be consistent, not only along the Atlantic, but for all coasts. Thus, the sand shorelines should not be viewed as straight lines but rather as a sinuous rhythmic line which may be nonstationary, tending to migrate along the coast. Dolan (1970) has shown that stable shoreline conditions may change rapidly toward less stable conditions as the crescentic forms advance along the shore. As long as the wide part of the form is positioned seaward of the structure, the structure may seem secure from erosion. However, as the crescentic forms move along the coast the same structure may become vulnerable to wave forces if positioned near the embayment where waves break at the beach. The Cape Hatteras Lighthouse shown in Figure 2, is an excellent example. This change in stability can occur without significant changes in wave or tidal conditions.

Therefore, positions of the shoreline, relative to any development, are not only determined by processes responsible for along-the-shore shoreline change. This variation is best determined from aerial photographs ranging in scale from 1:30,000 to 1:100,000. The smaller scales provide the coastal investigator with a clear view of regional relationships between crescentic segments of the shoreline.

In some areas a distinct HIERARCHICAL nesting of sand features seems to occur, with smaller crescentic features grouped within larger ones (Dolan and Ferm, 1968). Plate 1 illustrates this nested relationship. The 1:60,000 NASA color-infrared photo shows several large crescentic trends which, if magnified, show smaller crescentic forms. Figures 1 and 2 show examples of the intermediate sized sand waves.

In addition to the high-altitude photographs, the National Aeronautics and Space Administration, through regional centers along the Florida and Mississippi coasts, and at Wallops Island, Virginia, do provide high-quality, low-altitude photographs at scales of about 1:10,000 to 1:20,000 for selected investigations. Low-altitude color-infrared photographs of the barrier islands of Virginia and North Carolina have been used for examination of the hierarchical nesting of crescentic forms at different scales (Plate 2). Although the high-altitude imagery provides the large, regional overview, photographs at lower altitudes permits a finer analysis of the hierarchical nesting of smaller features, such as beach cusps, found within the crescentic features.

CONCLUSIONS

A significant amount of information concerning the state of the coastal environment can be obtained from high-altitude aerial photographs. By comparing photographic sequences, averaged conditions as well as rates of changes can be established. In addition, regional relationships provide an integration of the processes and sand responses occurring along the coast. For the most effective use of remote sensing, these data should be carefully coupled with lower-altitude photographs and ground-truth systems; however, remote sensing is the only method currently available for investigating the aerial and temporal distributions of crescentic coastal features.

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FOOTNOTES

[1] Assistance of the Geographic Applications Program, U.S. Geological Survey, and the National Aeronautics and Space Administration, Chesapeake Bay Ecological Program, Wallops Island, Virginia is gratefully acknowledged.

[2] High-altitude photographs have been used extensively to survey the geomorphology and hydrology of large areas. Recent examples of detecting and interpreting selected features in North Carolina and Arizona include the works of Sapp (1970) and Mairs (1970).

[3] For an excellent review of the application of large-scale aerial photography in coastal research, reference is made to: C.J. Sonu, "Study of Shore Processes with Aid of Aerial Photogrammetry," Photogrammetric Engineering, Vol. 30, No. 6, pp. 932-941, 1964.

[4] Three recent papers published in Photogrammetric Engineering discuss the use of color aerial photography: "Color for Metric Photogrammetry" (Vol. 34, No. 3, pp. 265-272, 1968); "Coastal Hydrography" (Vol. 34, No. 1, pp. 44-42, 1968); and "Color Photography for Water Resources Studies" (Vol. 34, No. 3, pp. 246-265, 1968).

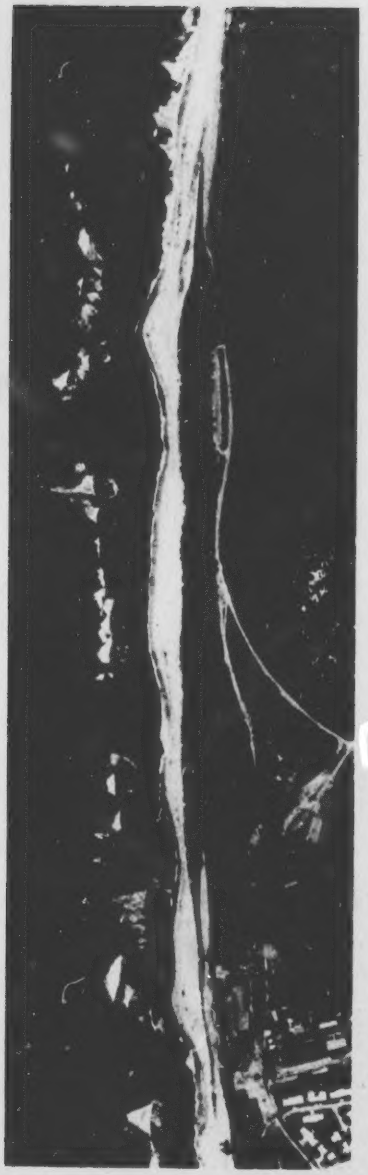

Figure 1. Sand wave field near Cape Hatteras, North Carolina.

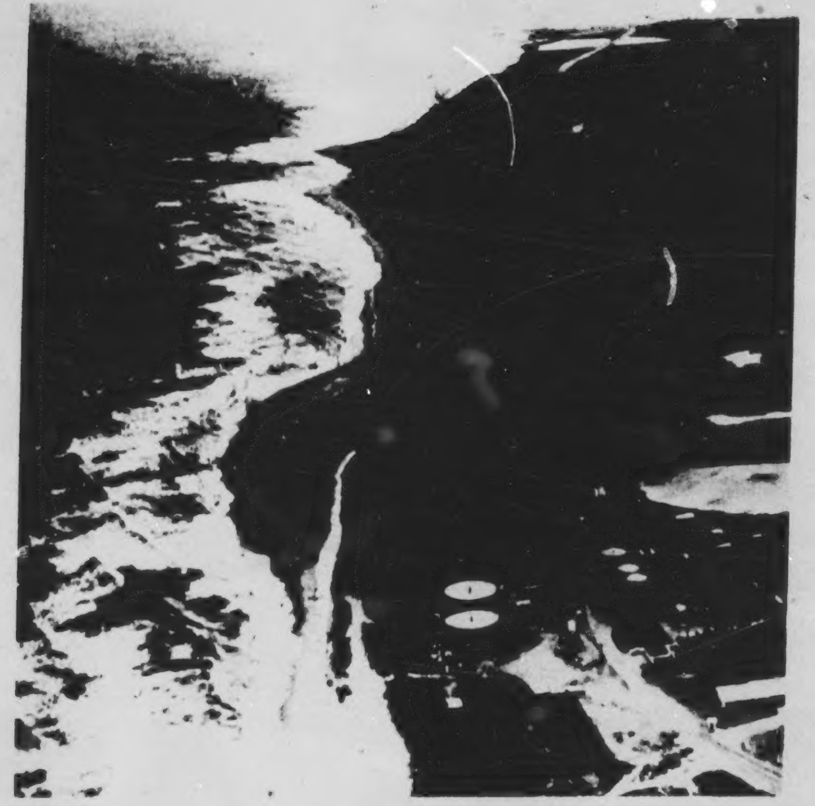

Figure 2. Concern about erosion may depend upon the relation between the structure location and the sand wave position. The Cape Hatteras Lighthouse is vulnerable at the time of this photo, but the large mass of sand in the foreground will migrate toward the point and the Lighthouse will then be secure for a time.

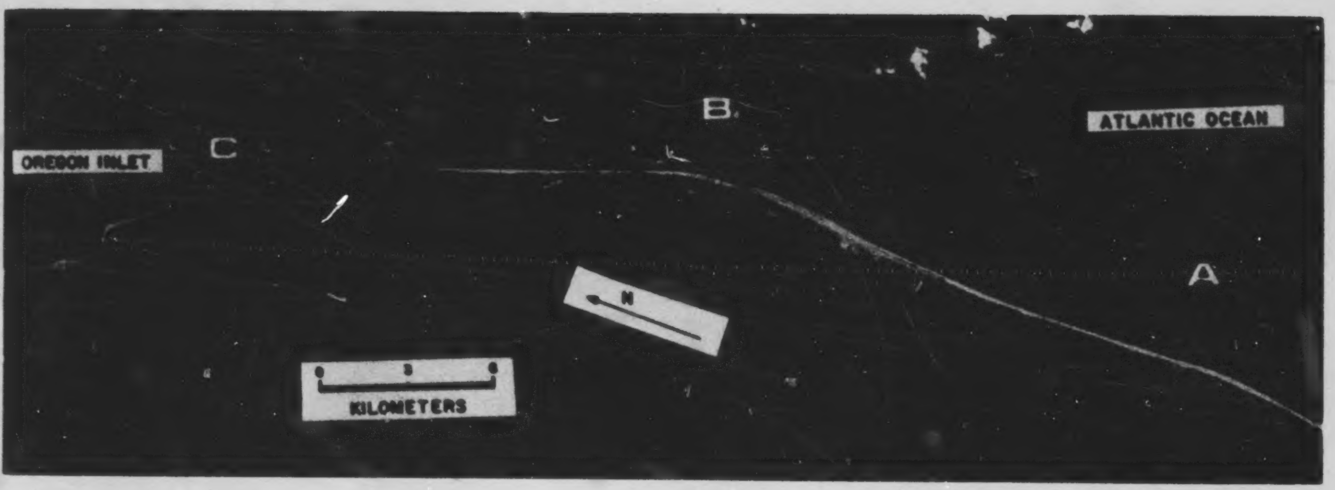
B
ATLANTIC OCEAN
C
OREGON INLET
A
N
0
3
6
KILOMETERS

PLATE 1. High-altitude photographs at a scale of 1:120,000 provide a base for investigation of large-size crescentic landforms. Near Oregon Inlet, North Carolina, crescentic features, both concave and convex, of size 15 and 20 kilometers are recognizable from the photographs (AB and BC). Under magnification smaller scale features are evident at B.

PLATE 2. Aerial photographs at a scale (original) of 1:10,000 provides sufficient resolution for measurement of shoreline sand waves. The spacing of the crescentic forms near Hatteras Village, North Carolina, A is 1,500 feet. Near the Cape Hatteras Lighthouse B, the spacing ranges from 508 to 1,500 feet. The combination of large-and small-scale aerial photography provides the coastal investigator with an excellent range of resolution for measurement of crescentic landforms.

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COASTAL PROCESSES

Vocabulary - Define the following terms in detail.

Sand waves
Shoreline rhythms
Sinuous curves
Crescentic
Submarine bars
Breakers
Barrier islands
1:60,000
Sand wave lengths
Wave amplitudes

Questions - Answer the following inquiries in detail.

1. Why are shorelines not straight?
2. What is the importance of crescentic coastal land forms?
3. How is a submarine bar formed?
4. What is the relationship of U-2 flights to Skylab and ERTS-1 data acquisition?
5. What are the rhythmic features of the Cape Hateras Beach area?
6. What conclusion did the author draw and why?

Discussion Topics

1. Explain sand dune formation as related to vegetation.
2. What effects do northeastern storms have on the local beaches?

MONITORING COASTAL WATER PROPERTIES AND CURRENT CIRCULATION WITH ERTS-1

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ABSTRACT

Imagery and DIGITAL TAPES from nine successful ERTS-1 passes over Delaware Bay during different portions of the tidal cycle have been analyzed with special emphasis on TURBIDITY, current circulation, waste disposal PLUMES and convergent boundaries between different water masses. ERTS-1 image radiance correlated well with SECCHI depth and suspended sediment concentration. Circulation patterns observed by ERTS-1 during different parts of the tidal cycle, agreed well with predicted and measured currents throughout Delaware Bay. Convergent shear boundaries between different water masses were observed from ERTS-1. In several ERTS-1 frames, waste disposal plumes have been detected 36 miles off Delaware's Atlantic coast. The ERTS-1 results are being used to extend and verify hydrodynamic models of the bay, developed for predicting oil slick movement and estimating sediment transport.

INTRODUCTION

Imagery and digital tapes from nine successful ERTS-1 passes over Delaware Bay during different portions of the tidal cycle have been analyzed with special emphasis on turbidity, current circulation, waste disposal plumes and convergent boundaries between different water masses. (NASA-ERTS-1 I. D. Nos. 1024-15073, 1079-51533, 1133-15141, 1187-15140, 1205-15141, 1294-15083, 1349-15134, 1385-15131, 1403-15125, respectively). During ERTS-1 overpasses gound truth has been collected for a total of twelve boat and helicopter transects across the bay, including measurements of Secchi depth, suspended sediment concentration and size, TRANSMISSIVITY, temperature, salinity, and water color. Three U-2 and four C-130 overflights took place during the same time period. Small aircraft equipped with clusters of filtered film cameras were used to underfly each ERTS-1 overpass.

PHYSICAL CHARACTERISTICS OF DELAWARE BAY

The Delaware Bay Estuary is a relatively prominent coastal feature which bounds the

Delmarva Peninsula on its northern side. The geography of this region, including the locations of several convenient reference points, is shown in Fig. 1. Trenton, New Jersey is generally taken to define the upper limit of the estuary, so that its total length is over 130 miles.

Fresh water input to the system is derived mainly from the Delaware River at an average rate of 11,300 cfs which, in terms of volume flow, ranks this as one of the major tributaries on the eastern coastal plain. Together with this large volume of fresh water, the river also discharges a heavy load of suspended and dissolved material, since its effective watershed encompasses an area typified by intensive land use, both agricultural and industrial (Oostdam, 1971). Seaward of the Smyrna River, the bay undergoes a conspicuous exponential increase in both width and cross-sectional area so that the strength of the river flow is rapidly diminished beyond this point. Ketchum (1952) has computed the flushing time of the bay (defined in this case as the time required to replace the total fresh water volume of the bay) to be roughly 100 days. Seasonal variations in river flow cause this figure to fluctuate within a range of from 60 to 120 days. Consequently, river flow is not a significant factor in determining the current pattern in the bay except in the consideration of time-averaged flow. In terms of short-period studies it is mainly important as a source of suspended sediment and contaminants.

The seaward boundary of the bay extends from Cape May southeast to Cape Henlopen -- a distance of eleven miles. Tidal flow across this boundary profoundly affects the dynamic and hydrographic features of the entire estuary. The effect is especially pronounced toward the mouth where conditions are generally well mixed. The dynamic behavior of the tides is closely approximated by the COOSCILLATING model described by Harleman (1966). In this model, the upper end of the estuary is assumed to act as an efficient reflecting boundary. Consequently, the actual tidal elevation at any given point is a result of the interaction of both a landward directed wave entering from the ocean and a reflected wave traveling back down the estuary. The tidal range is a maximum at the reflecting boundary and decreases toward the mouth in a manner dependent upon the relative phase of the two components. Observations of the tide at Trenton show a 7-foot range compared to a 4-foot range at the mouth. A relative maximum appears at roughly the location of Egg Island Point where the phase relationship is temporarily optimal. An important consequence of this behavior is the occurrence of strong reversing tidal currents in the Delaware River. The tidal wavelength as computed by Harleman, is 205 miles, so that both peak currents and slack water may occur simultaneously at either end of the bay.

The tidal flow is also modified by the bay's rather complex bathymetry (Fig. 1). Most prominent are several deep finger-like channels which extend from the mouth into the bay for varying distances (Kraft, 1971). Depths of up to 30 meters are present, making this one of the deepest natural embayments on the east coast. The channels alternate with narrow shoals in a pattern which is shifted noticeably toward the southern shore. On the northern side, a broad, shallow mudflat extends from Cape May to Egg Island Point. Considerable transverse tidal shears result from these radical variations in bottom contours. As a consequence, a marked GRADIENT structure may form normal to the main axis of the bay as a function of tidal phase. This intrinsic two-dimensional character, together with the complex, superimposed time variations, represents an almost insurmountable task when it is confronted with the tools of conventional hydrographic surveys.

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The problem is ready-made, however, for the techniques of high-altitude photography.

VISIBILITY OF SUSPENDED SEDIMENTS

Extensive investigations of suspended sediments in Delaware Bay and laser transmission tests in a test tank facility have been conducted respectively by (Oostdam, 1970, and Hickman, 1972). The results can be summarized as follows:

suspended sediments in Delaware Bay averaged 30 ppm. During July-August the average sediment level was 18 ppm.

turbidity increased with depth in the water column, except during periods of bloom, when surface turbidities at times exceeded those at greater depths.

suspended sediment concentration gradients were greater during ebb than during flood because of greater turbulence and better mixing during flood stage.

the turbidity decreased from winter to summer.

marked increases in turbidity which were observed during May and September were caused mainly by plankton blooms.

suspended sediments were silt-clay sized particles with mean diameters around 1.5 microns.

the predominant clay minerals are chlorite, illite and kaolinite.

reflectivities for the Delaware Bay sediments were measured to be about 10%.

At the time of the ERTS-1 overpasses, Secchi depth readings ranged from about 0.2 meters near the shore up to about 2 meters in the deep channel. Preliminary "equivalent Secchi depth" measurements with green and red boards indicated that neither "color" exceeded the readings obtained with the white Secchi disc. Therefore, it is quite unlikely that the bottom will be visible in any of the ERTS-1 channels and, at least in Delaware Bay, most of the visible features will be caused by light reflected off the surface or BACKSCATTERED from suspended matter.

"Red" filters, such as the Kodak Wratten No. 25A, have frequently been used in aerial photography to enchance suspended sediment patterns (Klemas et al., 1973, Bowker et al., 1973). In Delaware Bay red filters have been particularly effective for discriminating light-brown sediment-laden water in shallow areas from the less turbid dark-green water in the deep channel.

Figures 2 and 3 contain microdensitometer scans between Cape Henlopen and Cape May at the mouth of the bay. ERTS-1 images taken in bands 4, 5, and 6 were scanned, and grey scales equalized, to enable comparison on the same set of coordinate axes. Band 5 is clearly most sensitive to suspended sediment features. Even in band 5, however, the sediment patterns are caused by only four to five neighboring shades of grey in the negative transparencies and about twice that number in the digital tapes.

CORRELATION WITH MEASURED WATER PROPERTIES

During ERTS-1 overpasses ground truth was being collected with boats and helicopters along the three transects across the bay shown in Figure 4, including measurements of Secchi depth, suspended sediment concentration, transmissivity, temperature, salinity, and water color. The correlation between ERTS-1 MSS band 5 image radiance, Secchi depth and sediment concentration is shown tentatively in Figure 5. These measurements, including salinity and temperature shown in Figure 6, were obtained during the ERTS-1 overpass on January 26, 1973. Note the sharp discontinuities in salinity and temperature near aquatic boundaries.

During flood tide at the mouth of the bay, considerable correlation was found between the depth profile and image radiance, as shown in Figure 7. During flood tide most of the sediment in suspension seems to be locally generated over shoals and shallow areas of the bay resulting in a higher degree of backscatter from shallower waters.

CURRENT CIRCULATION PATTERNS

Since suspended sediment acts as a natural tracer, it is possible to study gross circulation in the surface layers of the bay by employing ERTS-1 imagery and predicted tide and flow conditions. Adjacent to ERTS-1 pictures, Figures 8, 9, 10, 11, and 12 contain tidal current maps for Delaware Bay. Each ERTS-1 picture is matched to the nearest predicted tidal current map within ± 30 minutes. A closer match was not attempted at this point, since quantitative comparison would require comprehensive current measurements over the entire bay at the time of each satellite overpass -- a feat not attainable with limited resources. The current charts indicate the hourly directions by arrows, and the velocities of the tidal currents in knots. The Coast and Geodetic Survey made observations of the current from the surface to a maximum depth of 20 feet in compiling these charts.

The satellite picture in Figure 8 was taken two hours after maximum flood at the entrance of Delaware Bay on October 10, 1972. The sediment pattern seems to follow fairly well with the predicted current directions. A strong sediment concentration is visible above the shoals near Cape May and in the shallow nearshore water of the bay. Peak flood velocity is occurring in the upper portion of the bay, delineating sharp shear boundaries along the edges of the deep channel. At the time of this ERTS-1 picture, the wind velocity was 7 to 12 miles per hour from the north.

Figure 9 represents tidal conditions two hours before maximum flood at the mouth of the bay observed by ERTS-1 on January 26, 1973. High water slick is occurring in the upper portion of the bay, resulting in less pronounced boundaries there as compared to Figure 8. The shelf tidal water is not rushing along the deep channel upstream anymore as in Figure 8, but is caught between incipient ebb flow coming down the upper portion of the river and the last phase of flood currents still entering the bay. The sediment plume directions in Figure 9 seem to show flood water overflowing the deep channel and spreading across the shallow areas towards the shore.

About six months later, on July 7, 1973, the ERTS-1 overpass shown in Figure 10 occurred during the same part of the tidal cycle as that shown in Figure 9. Since river flow differs in the winter and summer, Figures 9 and 10 enable one to compare the effect of river flow and wind effects with identical tidal conditions. The body of water having a higher radiance seen about 20 miles offshore in Figure 10 has not yet been explained.

As shown in Figure 11, on August 12, 1973, ERTS-1 passed over Delaware Bay one hour before maximum ebb at the mouth of the bay. In addition to locally suspended sediment over shallow areas and shoals observed in Figures 8 and 9, plumes of finer particles are seen in Figure 11 parallel to the river flow and exiting from streams and inlets off New Jersey's and Delaware's coastlines. Shear boundaries along the deep channel are still visible in the upper portion of the bay; however, they are beginning to disappear as slack sets in, resembling conditions in Figure 9. At the time of the overpass, the wind was from the north-northeast at about 11 miles per hour, possibly causing the streaks in the ocean off New Jersey's coastline.

The satellite overpass on February 13, 1973 occurred about one hour after maximum ebb at the capes. The corresponding ERTS-1 image and predicted tidal currents are shown in Figure 12. Strong sediment transport out of the bay in the upper portion of the water column is clearly visible, with some of the plumes extending up to 20 miles out of the bay. Small sediment plumes along New Jersey's coast clearly indicate that the direction of the longshore current drift in that area is towards the north. The wind velocity at the time of the satellite overpass was about 7 to 9 miles per hour from the north-northwest.

SHEAR BOUNDARIES AND SALINITY WEDGES

Boundaries or fronts (regions of high horizontal density gradient with associated horizontal convergence) are a major HYDROGRAPHIC feature in Delaware Bay and in other estuaries. Fronts in Delaware Bay have been investigated using STD sections, dye drops and aerial photography. Horizontal salinity gardients of 4% in one meter and convergence velocities of the order of 0.1m/sec. have been observed. Several varieties of fronts have been seen. Those near the mouth of the bay are associated with the tidal intrusion of shelf water (Figure 12). The formation of fronts in the interior of the bay (Figure 8) appears to be associated with velocity shears induced by differences in bottom topography with horizontal density difference across the front influenced by vertical density difference in the deep water portion of the estuary. Surface slicks and foam collected at frontal convergence zones near boundaries contained concentrations of Cr, Cu, Fe, Hg, Pb, and Zn higher by two to four orders of magnitude than concentrations in mean ocean water (Szekielda, Kupferman, Klemas, Polis, 1972). Figure 14, (Band 5, I.D. Nos. 1024-15073) obtained by ERTS-1 on August 16, 1972 contains several distinct boundaries. The southern-most boundary, as shown in Figure 15 is of particular interest, since it has frequently been observed from aircraft (Figure 16) and at the time of the ERTS-1 overpass. Divers operating down to depths of 6 meters noted increases in visibility from about half a meter to two meters as the boundary moved past their position.

WASTE DISPOSAL PLUMES

Careful examination of Figures 17 and 18 disclosed a fish-hook-shaped plume about 40 miles east of Cape Henlopen caused by a barge disposing acid wastes. The plume shows up more strongly in the green band than in the red band. Since some acids have a strong green component during dumping and turn slowly more brownish-reddish with age, the ratio of radiance signatures between the green and red bands may give an indication of how long before the satellite overpass the acid was dumped. Currently acid dumps are being coordinated with ERTS-1 overpasses in order to determine the diffusion and movement of the waste materials along the continental shelf.

IMAGE ENCHANCEMENTS AND DIGITAL MAPS

Color density slicing and optical additive color viewing techniques were employed to enhance the suspended sediment patterns. Grey tone variations were "sliced" into increments and different colors assigned to each increment by using the Spatial Data Datacolor 703 System at NASA's Goddard Space Flight Center. Color density slicing helped delineate the suspended sediment patterns more clearly and differentiate turbidity levels. Density slicing of all four MSS bands gave an indication of relative sediment concentration as a function of depth, since the four bands penetrate to different depths ranging from several meters to several centimeters, respectively.

Additive color composites of bands 4 and 5 were prepared by Photo-Science, Inc. using the photographic process silver-dye bleaching. This process bleaches out spectral separations of each MSS band to produce the color composite. The additive color rendition is then reproduced on Cibachrome CCT color transparencies. Comparison of the composite with the equivalent band 5 image in Figure 8 indicates that the composite does not contain more suspended sediment detail than the individual band 5 image. For similar reasons, composites prepared with the International Imaging Systems Mini-Addco Additive Color Viewer, Model 6030 did not improve contrast beyond what was attainable in band 5 directly.

ERTS-1 digital tapes are currently being used by Bendix Aerospace Systems Division to prepare annotated sediment concentration maps of the bay. GROUND TRUTH from at least one transect is used to annotate the maps.

CONCLUSIONS

ERTS-1 image radiance (microdensitometer traces) correlated well with Secchi depth and suspended sediment concentration. While only four concentration levels were extracted from transparencies, up to twice that number were obtained on sediment concentration plots derived from the MSS tapes directly. MSS band 5 seemed to give the best representation of sediment load in the upper one meter of the water column. Color density slicing helped delineate the suspended sediment patterns more clearly and differentiate turbidity levels. Density slicing of all four MSS bands gave an indication of relative sediment concentration as a function of depth, since the four bands penetrate to different depths ranging from several meters to several centimeters, respectively.

Circulation patterns observed by ERTS-1 during different parts of the tidal cycle, agreed well with predicted and measured currents throughout Delaware Bay. During flood tide the suspended sediment as visible from ERTS-1 correlated well with the depth profile. ERTS-1 imagery is now being used to extend and verify a predictive model for oil slick movement in Delaware Bay.

Convergent shear boundaries between diffrent water masses were observed from ERTS-1, with foam lines containing high concentrations of lead, mercury and other toxic substances. Several varieties of fronts have been seen. Those near the mouth of the bay are associated with the tidal intrusion of shelf water. Fronts in the interior of the bay on the Delaware side appear to be associated with velocity shears induced by differences in bottom topography. In several ERTS-1 frames, waste disposal plumes have been detected 40 miles off Delaware's Atlantic coast.

Applications of these results to relevant problem areas are listed in Table 1.

TABLE 1

	PARAMETERS DISCRIMINATED AND CORRELATED	APPLICATION TO COASTAL RESOURCES MANAGEMENT
1.	SUSPENDED SEDIMENT CONCENTRATION Band 5 correlated best with concentration and Secchi depth (transmissivity, temperature, salinity, color).	To verify and extend sediment transport model of Delaware Bay and monitor water quality. (U.D. and EPA).
2.	CURRENT CIRCULATION PATTERNS Good agreement with predicted current circulation as a function of tide and wind during 9 good overpasses.	To extend and verify predictive model for oil slick movement in Delaware Bay. (U.D. and NSF-RANN).
3.	WATER MASS BOUNDARIES Foam lines along convergent boundaries with toxic substances.	Boundaries used to modify hydrodynamic model of bay; toxic substances affect oyster beds. (U.D. and STATE).
4.	WASTE DISPOSAL PLUMES Greenish acid plume 36 miles off coast most visible in band 4.	Sludge and acid dumps coordinated with ERTS-1 overpasses to study dispersion of wastes dumped along continental shelf (U.D. and EPA).
5.	WETLANDS VEGETATION Maps of Delaware's wetlands completed showing 6 vegetation species and 3 other properties.	To develop marsh relative value model and plan wetlands development. (U.D. and STATE).
6.	LAND USE AND ENVIRONMENTAL IMPACT About 10 coastal land use categories mapped using ERTS digital tapes.	To monitor land use, its impact on marsh environment, and coastal erosion. (U.D. and STATE).

KEY: UD - University of Delaware
EPA - Environmental Protection Agency
NSF - National Science Foundation
RANN - Rann Corporation
STATE - State of Delaware

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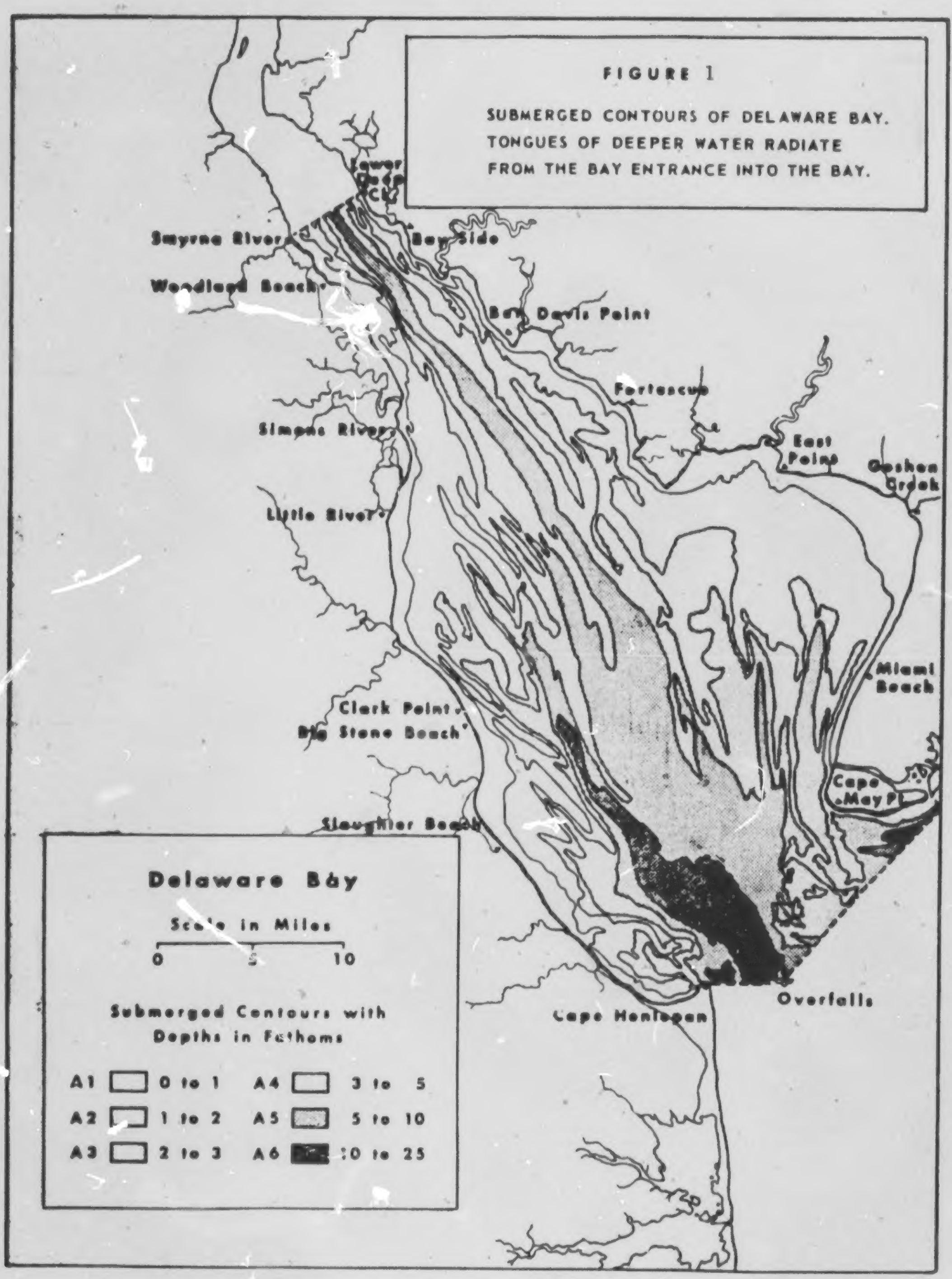
FIGURE 1
SUBMERGED CONTOURS OF DELAWARE BAY. TONGUES OF DEEPER WATER RADIATE FROM THE BAY ENTRANCE INTO THE BAY.
Smyrna River
Woodland Beach
Bay Side
Ben Davis Point
Simons River
Fortescue
East Point
Goshen Creek
Little River
Miami Beach
Clark Point
Big Stone Beach
Cape May Pt
Slaughter Beach
Overfalls
Cape Henlopen
Delaware Bay
Scale in Miles
0
5
10
Submerged Contours with Depths in Fathoms
A1 0 to 1
A2 1 to 2
A3 2 to 3
A4 3 to 5
A5 5 to 10
A6 10 to 25

Figure 1
Submerged Contours of Delaware Bay

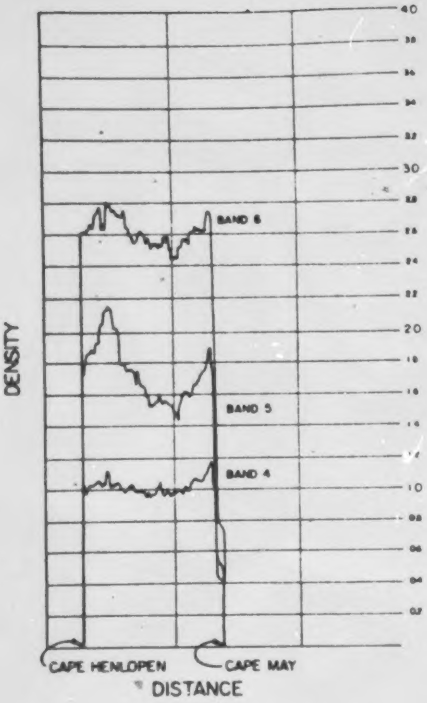

Figure 2 - Positive transparencies

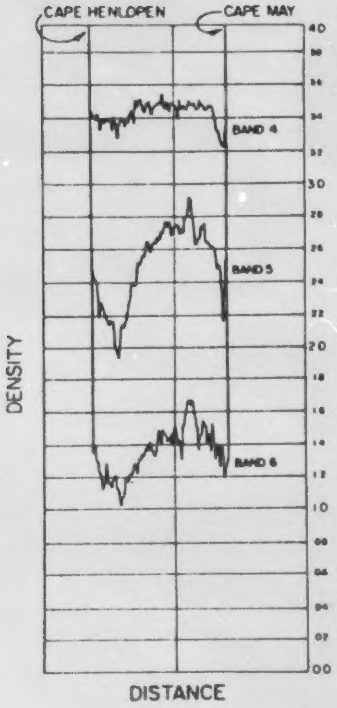

Figure 3 - Negative transparencies

Microdensitometer traces of October 10, 1972, ERTS-1 imagery from Cape Henlopen, Delaware to Cape May, New Jersey, using MSS bands 4, 5 and 6.

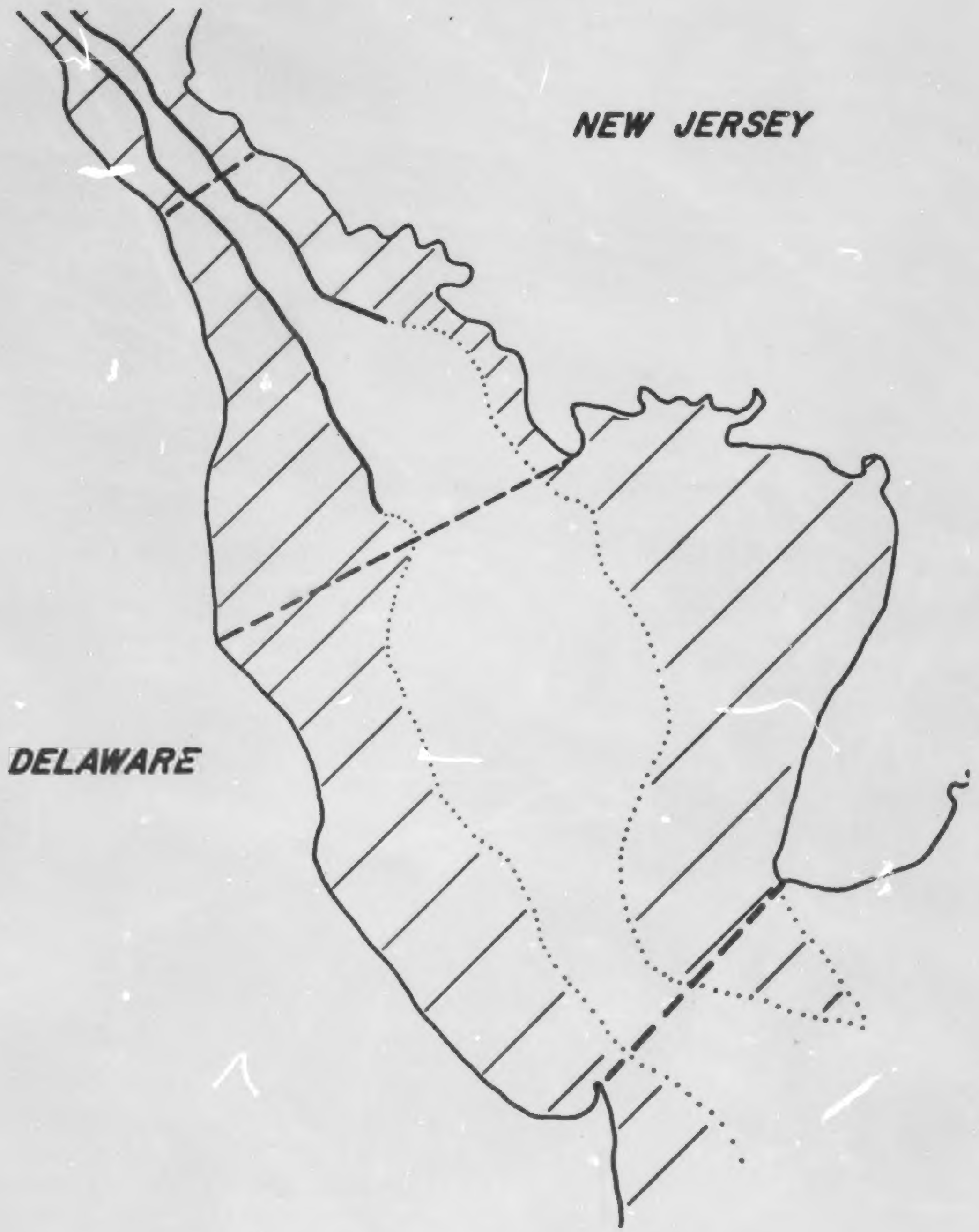

Figure 4 - Helicopter and boat transects across Delaware Bay along which Secchi depth, sediment concentration, transmissivity, temperature, salinity and water color were measured during ERTS-1 overpasses.

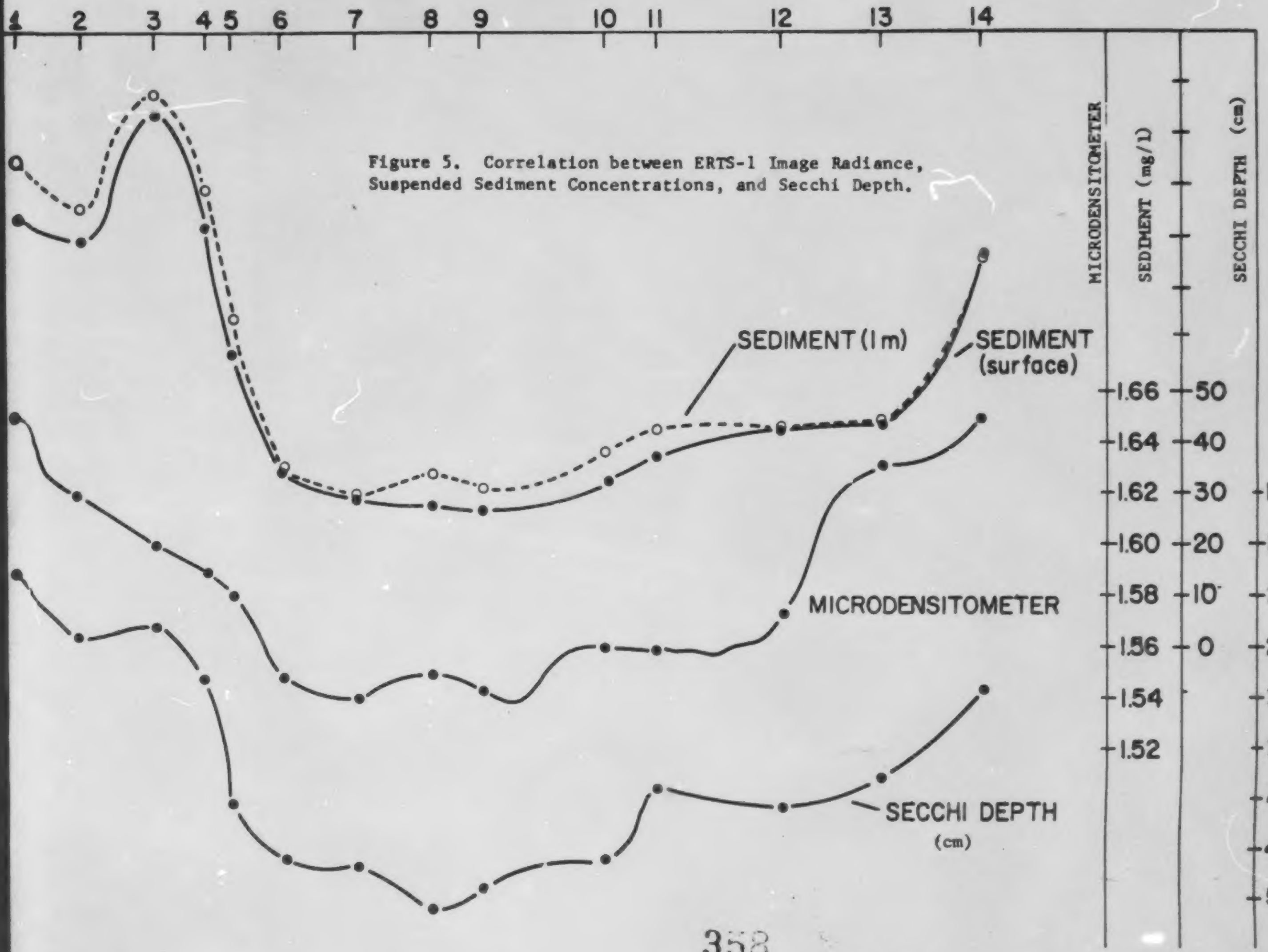

Figure 5. Correlation between ERTS-1 Image Radiance, Suspended Sediment Concentrations, and Secchi Depth.

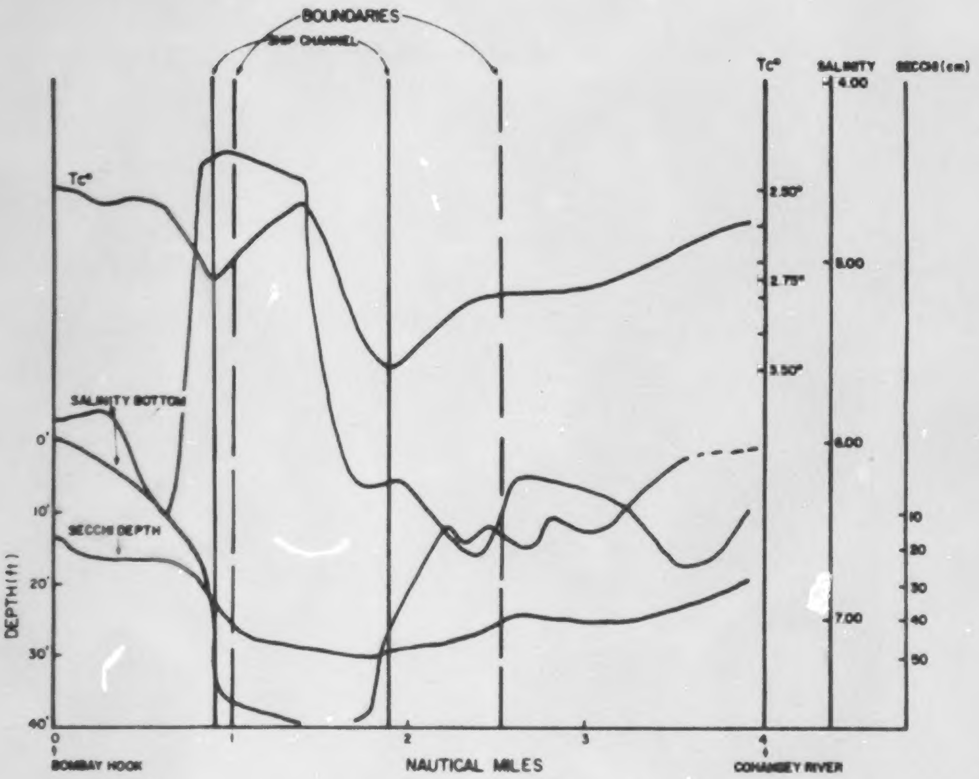

Figure 6. Temperature, salinity Secchi depth and bottom profiles across the upper transect of the bay during ERTS-1 overpass on January 26, 1973.

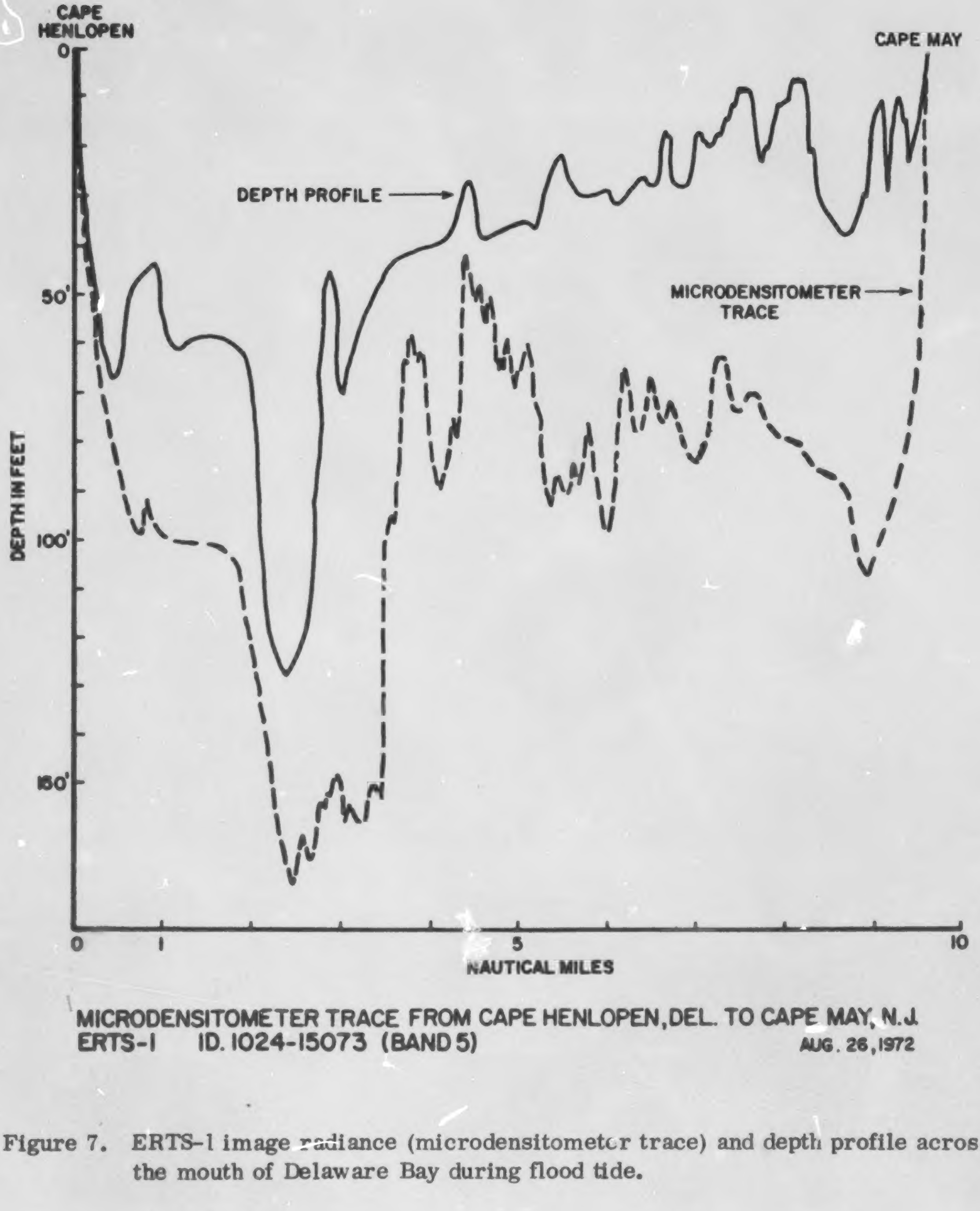

Figure 7. ERTS-1 image radiance (microdensitometer trace) and depth profile across the mouth of Delaware Bay during flood tide.

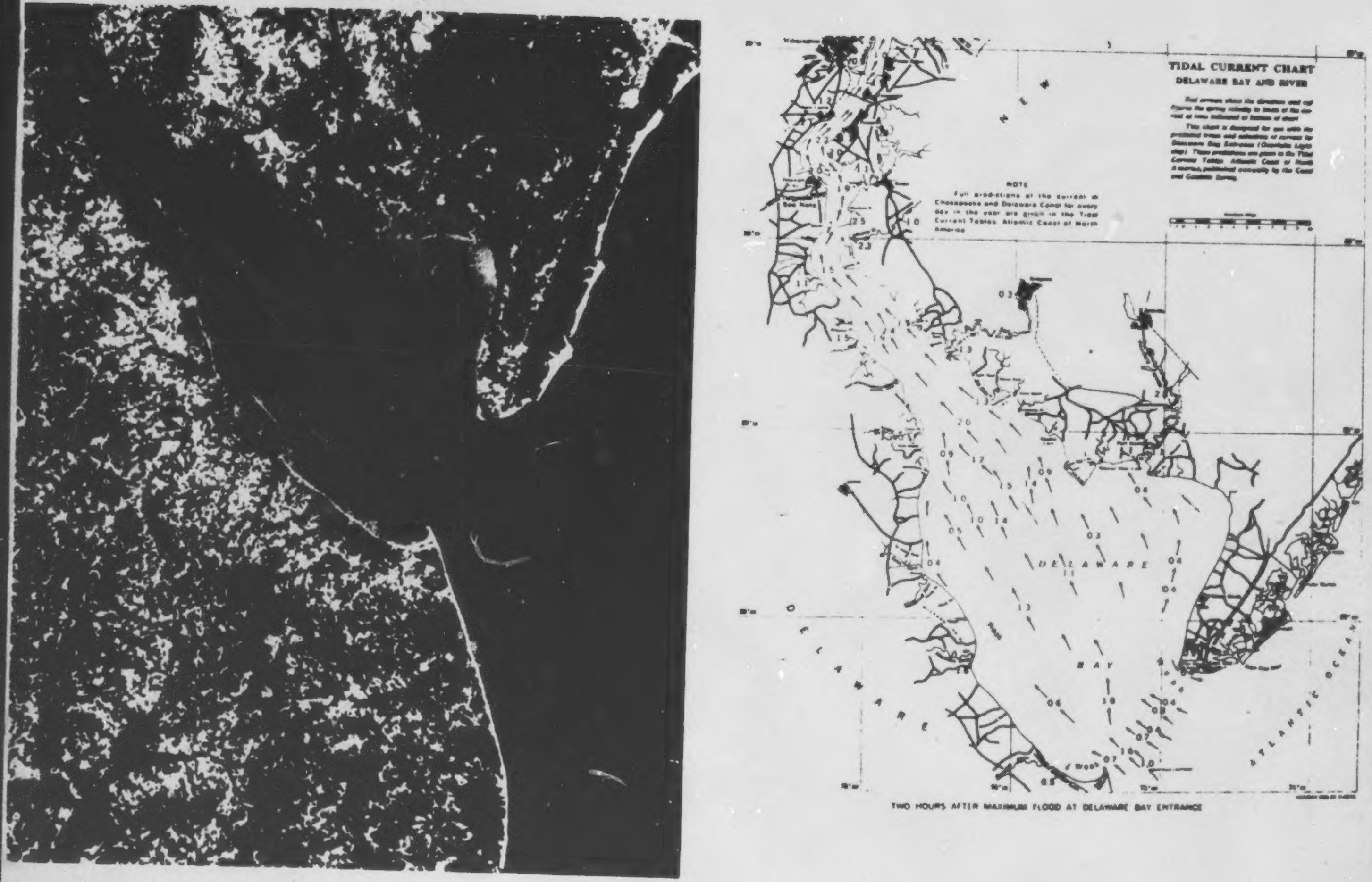
TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
NOTE
Full predictions of the current in Chesapeake and Delaware Canal for every day in the year are given in the Tidal Current Tables Atlantic Coast of North America
DELAWARE
BAY
DELAWARE
ATLANTIC OCEAN
TWO HOURS AFTER MAXIMUM FLOOD AT DELAWARE BAY ENTRANCE

Figure 8. ERTS-1 image of Delaware Bay obtained in MSS band 5 on October 10, 1972 and tidal current map. (I. D. No. 1079-15133).

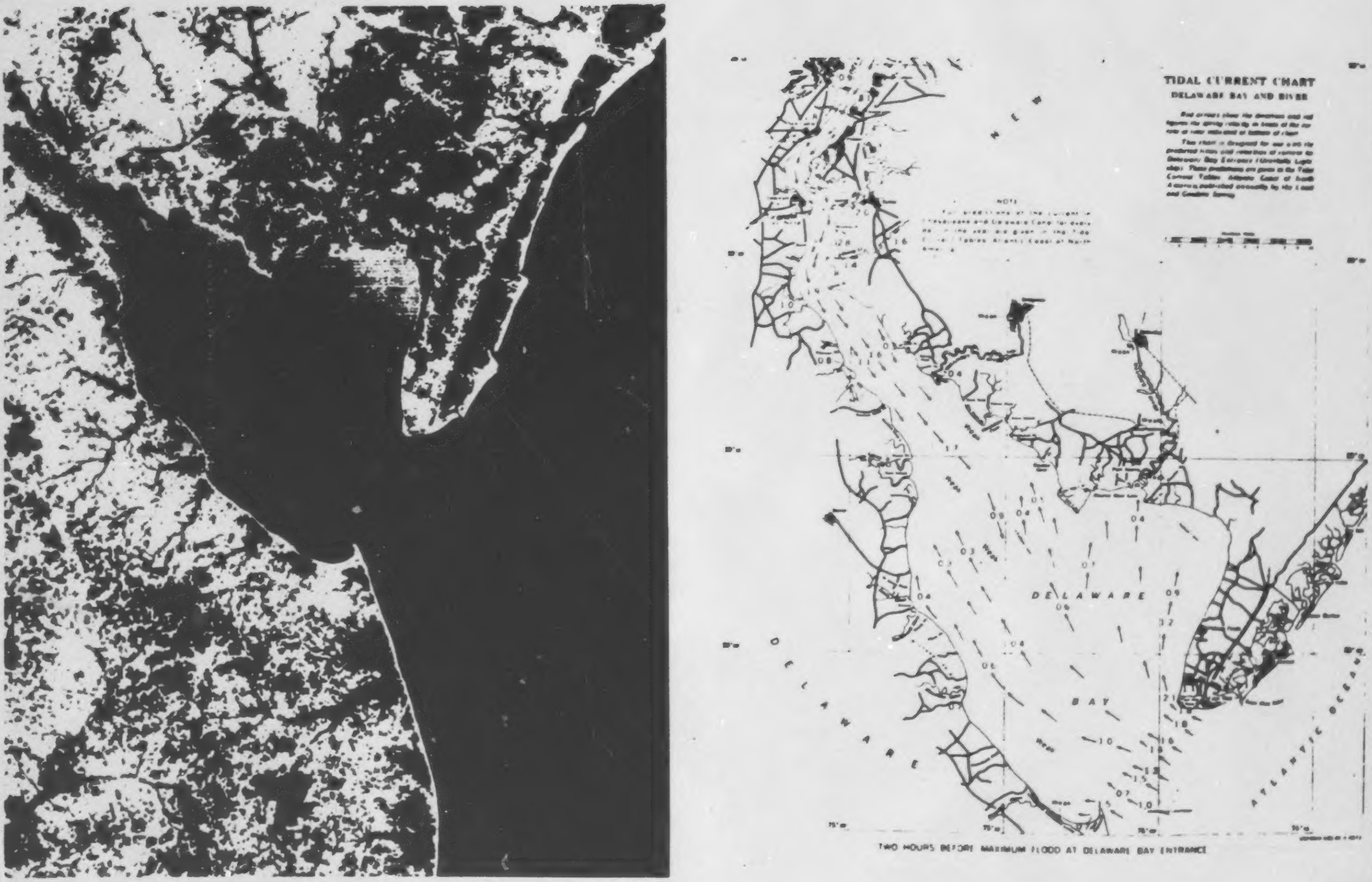
TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
NOTE
DELAWARE
BAY
DELAWARE
ATLANTIC OCEAN
TWO HOURS BEFORE MAXIMUM FLOOD AT DELAWARE BAY ENTRANCE

Figure 9. ERTS-1 image of Delaware Bay obtained in MSS band 5 on January 26, 1973 and tidal current map. (I. D. Nos. 1187-15140).

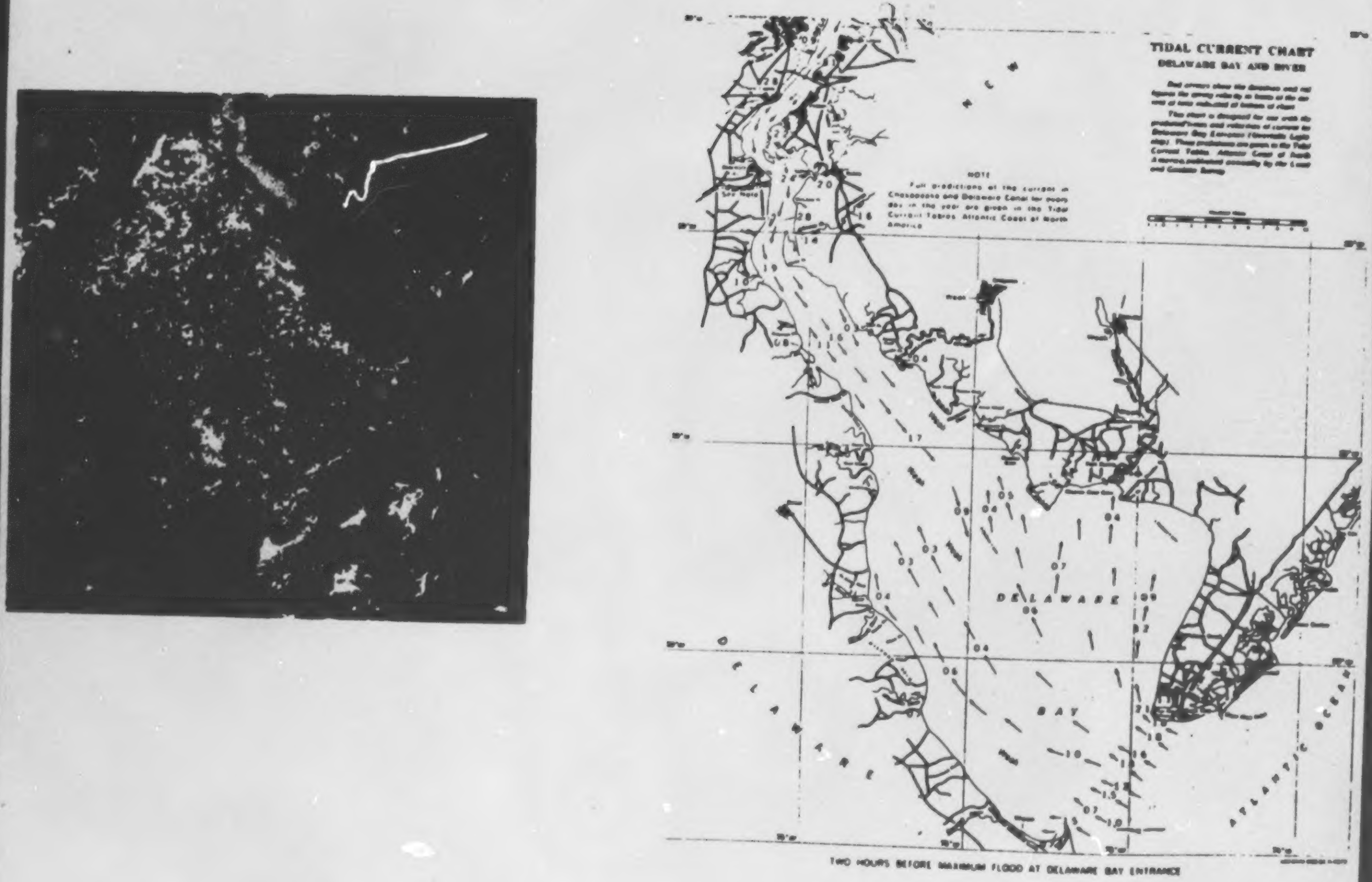
TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
NOTE
Full predictions of the current in Chesapeake and Delaware Canal for every day in the year are given in the Tidal Current Tables Atlantic Coast of North America
DELAWARE
BAY
DELAWARE
ATLANTIC OCEAN
TWO HOURS BEFORE MAXIMUM FLOOD AT DELAWARE BAY ENTRANCE

Figure 10. ERTS-1 image of Delaware Bay obtained in MSS band 5 on July 7, 1973 and tidal current map. (I. D. Nos. 1349-15134).

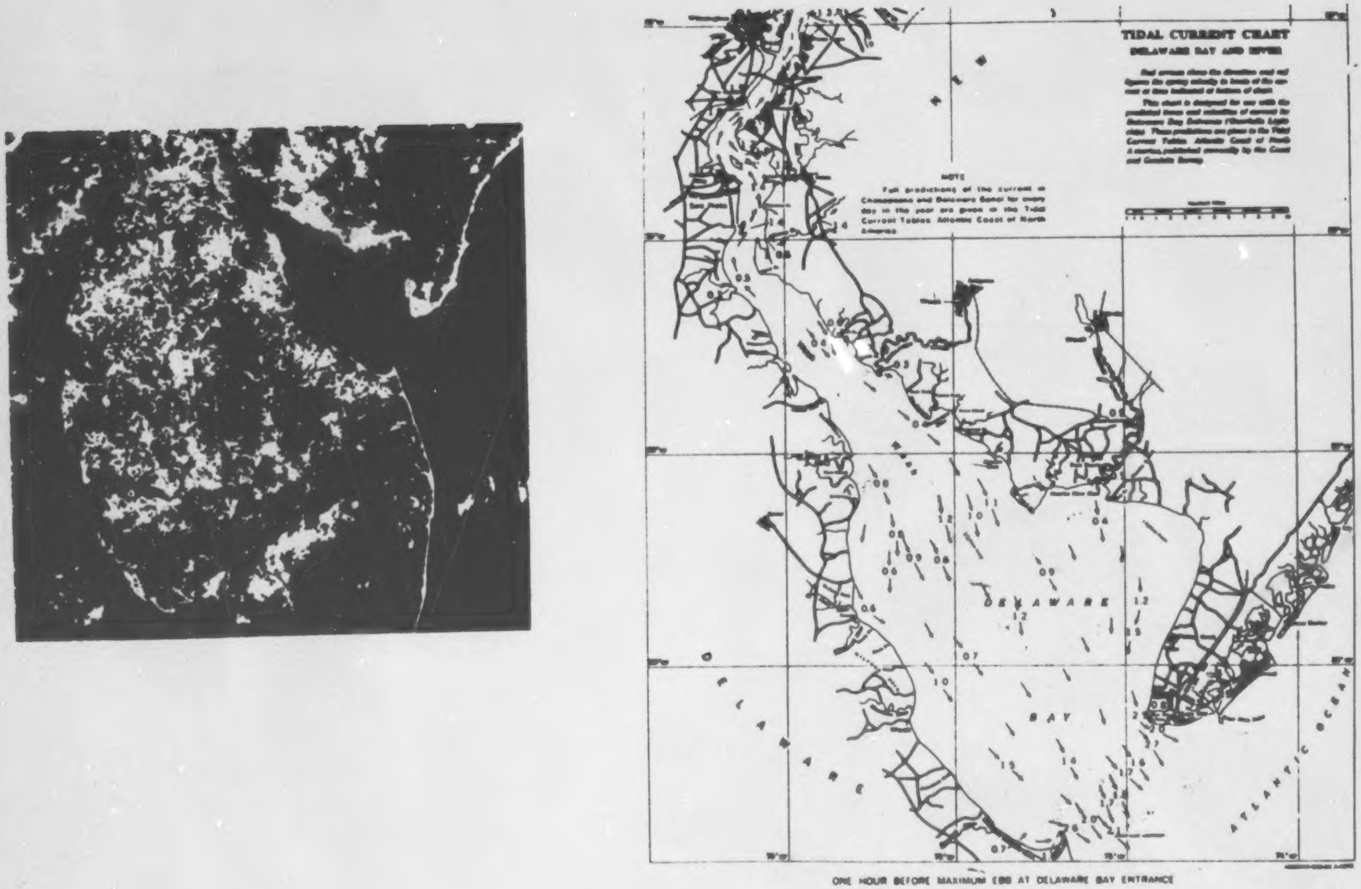
TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
NOTE
Full predictions of the current in Chesapeake and Delaware Canal for every day in the year are given in the Tidal Current Tables Atlantic Coast of North America
DELAWARE
BAY
DELAWARE
ATLANTIC OCEAN
ONE HOUR BEFORE MAXIMUM EBB AT DELAWARE BAY ENTRANCE

Figure 11. ERTS-1 Image of Delaware Bay taken with MSS band 5 on August 12, 1973 and tidal current map. (I. D. Nos. 1385 - 15131.)

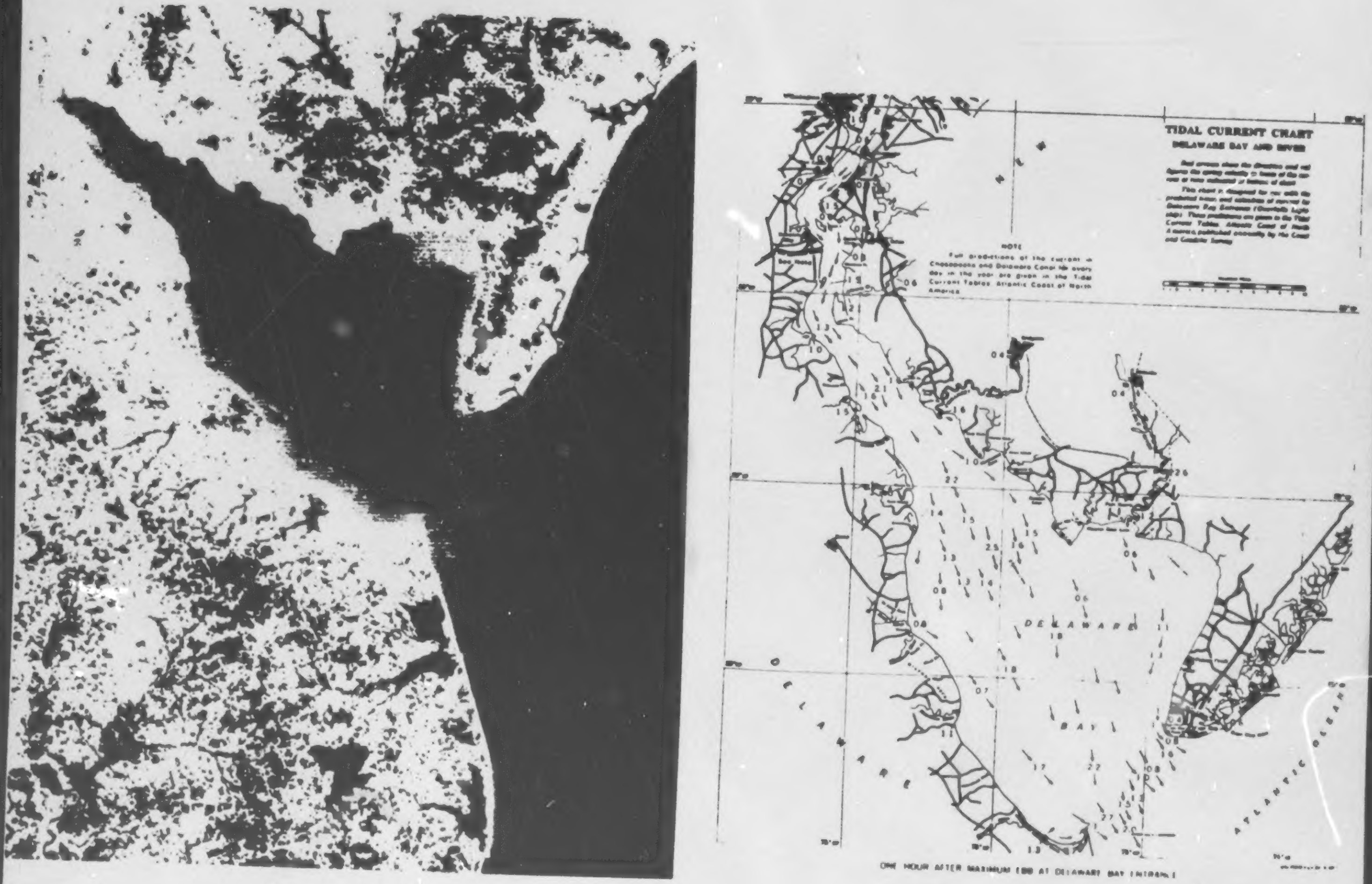
TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
NOTE
Full predictions of the current in Chesapeake and Delaware Canal for every day in the year are given in the Tidal Current Tables Atlantic Coast of North America
DELAWARE
BAY
DELAWARE
ATLANTIC OCEAN
ONE HOUR AFTER MAXIMUM EBB AT DELAWARE BAY ENTRANCE

Figure 12. ERTS-1 Image of Delaware Bay obtained in MSS band 5 on February 13, 1973 and tidal current map. (I. D. Nos. 1205 - 15141.)

Figure 13. Frontal system caused by higher salinity shelf water intruding into Delaware Bay.

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Figure 14. ERTS-1 Image of the mouth of Delaware Bay showing several water mass boundaries and high concentrations of suspended sediment in shallow waters. (Band 5, August 16, 1972, I.D. No. 1024 - 15073).

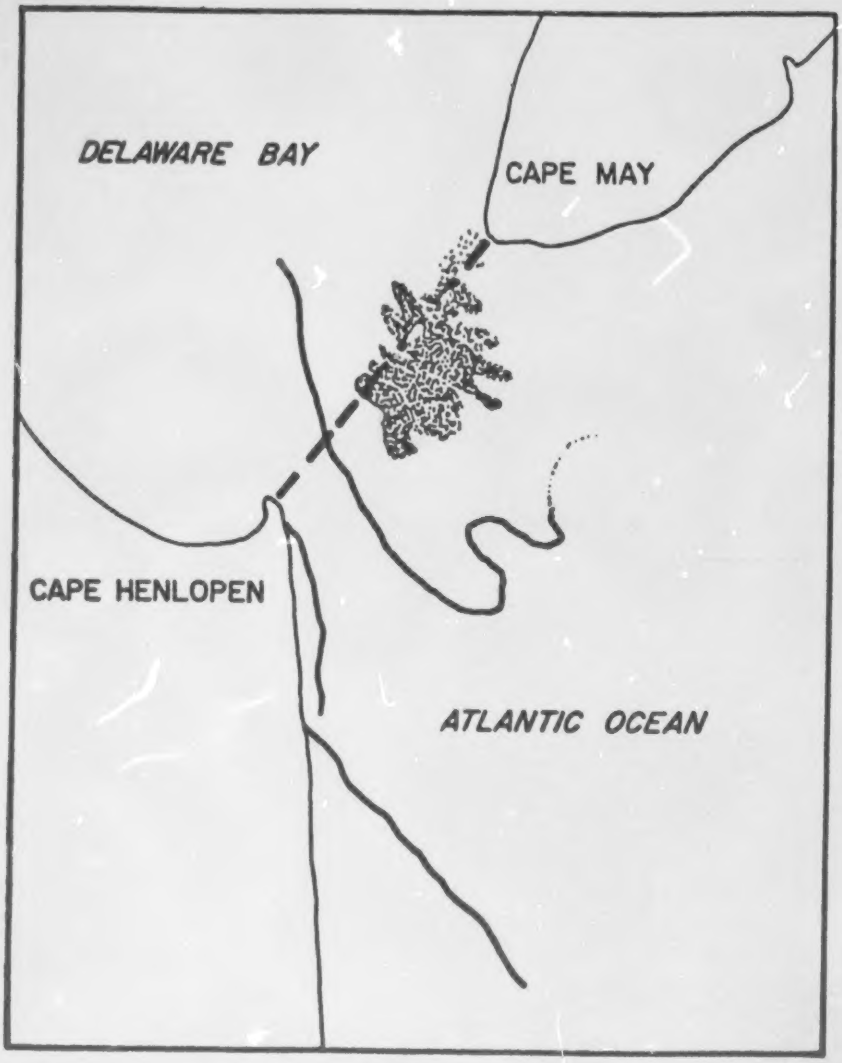
DELAWARE BAY
CAPE MAY
CAPE HENLOPEN
ATLANTIC OCEAN

Figure 15. Aquatic boundaries and suspended sediment plumes identified in the ERTS-1 image of August 16, 1972, shown in Figure 14.

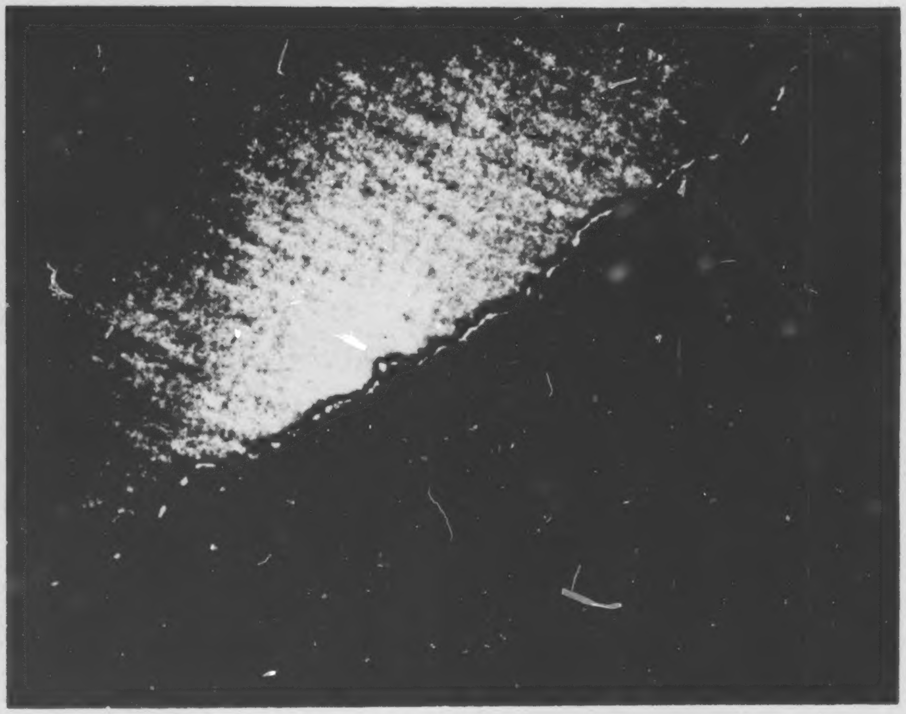

Figure 16. Aerial photograph from 9000 feet altitude of foam line at boundary between two different water masses off Delaware's coast.

Figure 17. Acid waste dumped from barge about 40 miles east of Indian River Inlet appears clearly as a fishhook shaped plume in MSS band 4 image of January 25, 1973.

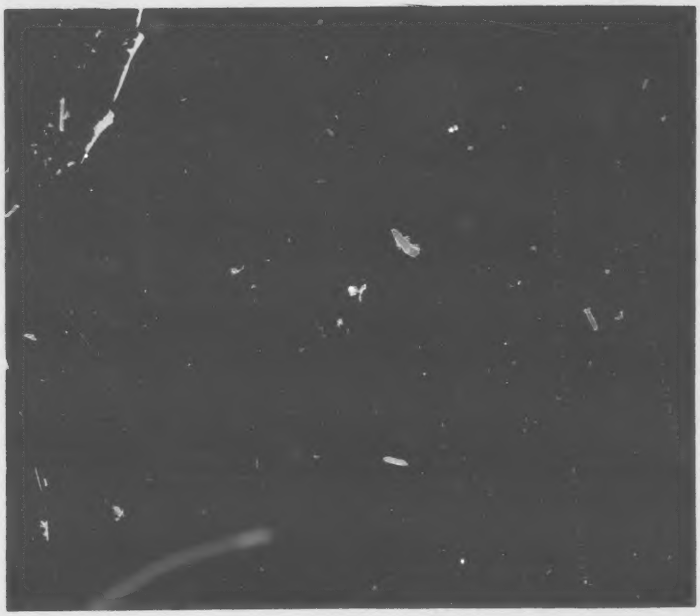

Figure 18. Due to its predominantly greenish component, the acid plume shows less contrast in band 5.

COASTAL WATER

Vocabulary - Define the following terms in detail.

- Digital tape
- Current circulation
- Turbidity
- Waste disposal plumes
- Secchi
- Hydrodynamics
- Aerial photography
- Transect
- Estuary
- Water shed
- Tidal flow
- Bathymetry
- Suspended sediments
- Tidal Shears
- Plumes
- Shoals

Questions - Answer the following inquiries in detail.

1. What are the physical characteristics of Delaware Bay?
2. What is a Secchi disc?
3. Why did turbidity decrease from winter to summer?
4. What overall conclusions were reached in the visibility of suspended sediments?
5. Why did circulation patterns observed by ERTS-1 agree with predicitions of circulation in Delaware Bay?
6. What chemicals were found in surface slicks and foam? Why?
7. How does ERTS-1 help in the tracking of acid plumes?
8. Why is it important to know the wind velocity and direction at the time of the satellite pass?

Discussion Topics

1. Explain the effects of an on-shore wind on a **pollution plume.**
2. How do circulation patterns of water movement affect fish migration?

A FEASIBILITY DEMONSTRATION OF AERIAL PHOTOGRAPHIC SUPPORT FOR MARINE ARCHEOLOGICAL SURVEYS

Principal Investigator
A. D. MARMELSTEIN

Earth Satellite Corporation

Report to Division of Archeology,
National Park Service on
Project No. 14X3910

ABSTRACT

A feasibility demonstration was undertaken over Loggerhead Reef in Fort Jefferson National Monument to determine the utility of aerial photography in support of marine archeological surveys. Photography was obtained on a 70 mm format using five film/filter combinations. The five combinations evaluated were conventional color, both haze filtered and unfiltered, false color infrared with Wratten 15 filter, blue insensitive color with Wratten 15 filter, and panchromatic with Wratten 12 filter.

In the clear waters predominating in the national monument, conventional color provides ample depth penetration. However, both minus-blue filtered color films showed potentially greater depth penetration capability for turbid water conditions. Several sites containing significant remains were identified, including one previously unlocated site containing perhaps the most important remains in the national monument.

Coordinated use of both large and small scale photography proved particularly useful for precisely locating newly identified sites, and for providing the capability to easily relocate previously identified sites. This latter capability is particularly noteworthy in that existing charts contain numerous errors which complicate the task of relocating a site.

It is recommended that aerial techniques be used in concert with more conventional survey techniques, especially in that aerial techniques are presently unmatched in the dimension they provide for precise location of sites. Further, interpretation of photography obtained prior to ground survey should occur simultaineously with ground survey procedures in order to increase the likelihood of convergent evidence providing identification and location of unknown sites.

INTRODUCTION

One of the most basic, and frequently most difficult, tasks of the historical archeologist is to detect the presence of a site, known or unknown, occupying a small portion of a large, rather uniform area. This is especially true when the site occurs in the marine environment, even if it lies in relatively shoal water. Such is the case in the area encompassing Fort Jefferson National Monument, located in the Dry Tortugas, approximately 70 miles due west of Key West, Florida, at latitude 24°38'N, longitude 82°58'W. This shoal area is a grouping of coral reefs and low-lying sand islands marking the western extreme of the formation of reefs and islands commonly known as the Florida Keys. The largest island (Loggerhead Key) and the island upon which Fort Jefferson is built, are shown in Figure 1.

Perhaps the most significant feature of the Dry Tortugas, especially from the point of view of historical archeology, is that the reefs lie athwart, or adjacent to, the major shipping routes which converged on Havana from the northern New World, so that ships began foundering on the reefs, for a variety of reasons, from the period of earliest colonization by the Spaniards. Such occurrences have continued through the settling of the New World, the American Revolutionary period, the Civil War, and indeed into recent years. Thus, the reefs hold a vast quantity of ships and materials capable of documenting at least four centuries of civilization in the New World.

The fact that remains of archeological significance are spread over some 50 square miles of reef area afforded the opportunity to determine whether aerial remote sensing techniques could be used to detect uncharted sites. The project described herein is a feasibility demonstration of a method for discovering and precisely locating at least some of the numerous remains in Fort Jefferson National Monument. It is expected that the techniques developed will be applicable to other submerged areas of interest to the National Park Service and other cooperating state and federal agencies, and will complement present survey procedures.

METHODS

In that the present study was undertaken as a feasibility demonstration, it was determined initially to survey by aerial photography a small (5 square mile) region of the national monument previously surveyed by more conventional techniques, and containing known sites of archeological significance. Thus, the area known as Loggerhead Reef was chosen as the ground target. For purposes of alignment and location, flight lines were extended to include a section of Loggerhead Key to the northeast of the target area (Figure 1).

Since the proposed application of aerial photography had not previously been attempted, it was determined to experiment with five film/filter combinations in a MULTI-SPECTRAL, four camera assembly. Thus, four electric Hasselblad Cameras (Model 500EL) were used to obtain simultaneous coverage with the film/filter combinations described in Table I. Photography was obtained through subcontract to Environmental System Corporation, Knoxville, Tennessee. To insure adequate coverage, each flightline was overflown twice. During the second pass, the conventional color was exposed without a filter, thereby providing the fifth combination.

Problems with cloud cover, as well as pilot error, resulted in a variable flight altitude averaging 2,000 feet. Therefore, the scale of the photography approximates 1:7600. A further problem developed when it was realized that the camera system could not be adequately isolated from aircraft vibration. The expectation of deteriorating weather (a tropical storm approaching from the northern Caribbean) precluded any delay to modify the system. As expected, all of the film, on being processed and inspected, demonstrated considerable image degradation due to vibration. This was particularly evident on the aerial ektachrome (type 2448), as proper exposure of this film required a slower shutter speed than that used for the other films. The blurring present on all photography had a concomitant effect on interpretability, considerably decreasing the utility of the photography.

Film	Filter	Rationale
Conventional Color (Eastman Kodak Aerial Ektachrome, Type 2448)	None/Haze	This film was used in order to obtain photography whose appearance was as close, in terms of color tonal contrast, to that seen by the eye, as possible.
False Color Infrared (Eastman Kodak Aerochrome Infrared, Type 2443	Wratten 15	This film is filtered to be insensitive to blue light. It was used to attempt to intensify the tonal contrast in the red and green regions of the spectrum where most of the information content in upwelling light occurs. Blue light, although predominant in upwelling light, primarily occurs through scattering, hence carries relatively little information. Over water, little or no solar infrared is backscattered, hence the film was not used for its infrared sensitivity, but for its blue insensitivity.
Blue Insensitive Color (GAF 1000 Blue Insensitive Color Aerial Film)	Wratten 15	This experimental film offers the same advantages as the preceding, being filtered to eliminate scattered blue light, hence improving water penetration. Unlike the preceding type, it is not routinely available.
Panchromatic (Eastman Kodak Plus X Aerographic, Type 2402)	Wratten 12	This film was filtered to remote blue, thus gaining the advantages listed previously. It was used to provide black and white prints for both interpretation and reporting purposes.

Table I Film/Filter Combinations

RESULTS AND RECOMMENDATIONS

Each frame of the various films exposed over the test area was examined both to assess the comparative virtues of each type for favorably portraying the submerged reefs, as well as to determine if targets of archeological significance were present. With one exception intensive interpretation was limited to the frames obtained over Loggerhead Reef.

Several striking features are apparent from the photography. Of prime concern is the ability of each film/filter combination to penetrate the water column. Examination of the films indicated that in the Dry Tortugas water clarity is of such high quality that all film/filter combinations adequately portray bottom features, especially in the shoal areas of prime importance to this study. However, as water depth increases, the bottom remains clearly visible in the blue insensitive film in areas where it begins to fade on the conventional photography. Indications are that color infrared film, appropriately filtered, would also offer considerable utility for water penetration. However, exposure indices for the latter film are based heavily on the solar infrared sensitivity of the film. Since this portion of the spectrum is of no use in submerged applications due to intense absorption by seawater of light at these wavelengths, the film should be overexposed to utilize its water penetrating ability. The film used for this study was exposed in the normal fashion, hence was underexposed with respect to the spectral bands of interest.

For future application in the shoal waters of Fort Jefferson National Monument, use of conventional color film, unfiltered, would be fully acceptable for survey purposes. For areas where more turbid conditions prevail, careful application of the blue insensitive/blue filtered color films is indicated.

Intensive interpretation of the photography was limited to two areas, one inside the target area, the other outside. Both areas yielded information of considerable importance.

Figure 2 is a three times enlargement of one frame from the target area on Loggerhead Reef. Although identified features are indicated on the figure, they are not as sharply defined here as on the companion color transparencies, due to the absence of subtle color tonal differences on the black and white reproduction. The location of the subject frame is indicated as position one on Figure 4. The features outlined are believed to be pieces of ships' rigging, materials, and armament strewn across several thousand square meters of reef by the breakup of several vessels. This area corresponds to a previously identified site, the "Nine Cannon Wreck" site. Identifications indicated were made before the interpreter knew of the exact nature of this site. The positioning of this site on the small scale photography represents a considerably more precise location for the Nine Cannon Wreck site than had been obtained by the survey party using conventional surface techniques.

This frame, as do many others over the target site, contains evidence of tracks cut into the coral as ships of various sizes were swept onto the reefs. In the subject frame, the narrow white line projecting nearly parallel to the margin at the bottom center is the track cut recently by a small sail boat running onto the reef. Larger tracks in other areas may have been caused by larger or older wrecks. The slow growth of coral polyps, as well as the scouring effect of sand, serve to preserve these tracks, perhaps for centuries in extreme cases. In any event, the tracks are secondary evidence pointing to areas for prime consideration as wreck sites.

Figure 3 is a three times enlargement of a frame outside the prime target area. During cursory examination of the frames in this area, an unusual feature was immediately detected. As outlined on the figure, a curvilinear feature, whose shape contrasts sharply with the predominantly linear features of the surrounding area, lies on the main reef-face. Although this area is outside the main ground survey area, several convergent lines of evidence suggest that it may well be the single most important wreck site in the national monument.

During a period when the proton magnetometer (an instrument used to survey for wrecks based on the disturbance of the background magnetic field due to the presence of base metals) was not engaged in the target area, it was towed northeast and recorded a large ANOMALY near the site given above. Swimmer inspection of the anomalous area yielded positive identification of ballast stones and other artifacts over a broad area. This photography, however, when keyed to the small scale USGS photography (Figure 4, Position 2) represents the first precise location of the site or sites (another frame with suspicious ground features covers an area centered about 1/2 mile northeast of the center of Figure 3, and can also be positively located on the small scale photography) which may contain the remains of the 17th century Spanish galleon "Nuestra Senora del Rosario", known to have been lost in the Dry Tortugas. As in the previous example, discovery of this site was made prior to access to, or knowledge of, any of the supportive evidence. Naturally, the tentative naming of the site followed correlation of all available pieces of evidence.

The brief review of the results obtained adequately demonstrates the feasibility for archeological surveying in the marine environment through the use of aerial remote sensing systems. In particular, the project, although undertaken hastily due to declining weather conditions, hence producing primary data considerably less than optimum, has resulted not only in identifications of significant archeological sites, but equally as important, has provided for the first time an accurate means of locating, and a precise means of relocating, each site. It is equally evident, however, that such a technique should not be undertaken as the sole surveying technique. Rather, these aerial techniques strongly complement the standard techniques, especially in their ability, unmatched by the standard survey techniques, to provide a reliable basis for relocating identified sites. It is therefore recommended that an aerial survey be adopted as routine support for the ongoing marine archeology survey in Fort Jefferson National Monument. Further, the photographic support mission should be designed to provide both small scale (about 1:24000 and large scale (about 1:5000 to 1:10000) photography, the latter for identification, the former for location. Support of this kind will become particularly important as the survey moves onto the northeast reef (Pulaski Shoals), where location by standard techniques will become nearly impossible due to the absence of any emergent areas for surface triangulation.

It is further recommended that the photography be acquired prior to ground survey, so that interpretation can proceed at the time of ground survey, and can be coordinated with the application of other techniques, such as the magnetometer transects. This timing is particularly important in that existing charts of the national monument contain numerous inaccuracies. Therefore, all positioning should be accomplished and coordinated from the aerial photography.

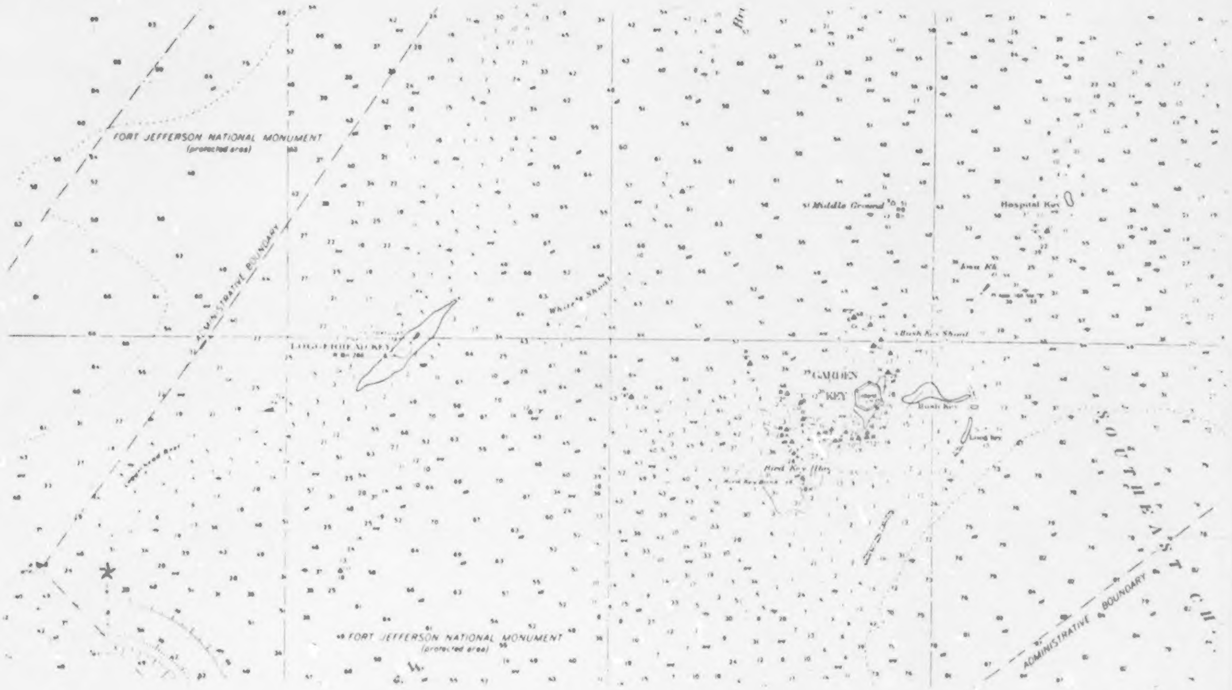
FORT JEFFERSON NATIONAL MONUMENT
(protected area)
ADMINISTRATIVE BOUNDARY
LOGGERHEAD KEY
Middle Ground
Hospital Key
Bush Key Shoal
GARDEN KEY
Bush Key
Bird Key
FORT JEFFERSON NATIONAL MONUMENT
(protected area)
ADMINISTRATIVE BOUNDARY
SOUTHEAST CH

Figure 1. A portion of National Ocean Survey chart 585, showing the Loggerhead Key region of Fort Jefferson National Monument. Flight line positions are nominal.

Editors' Note: At the request of the National Park Service, flight lines and other position markers locating wreck sites have been deleted.

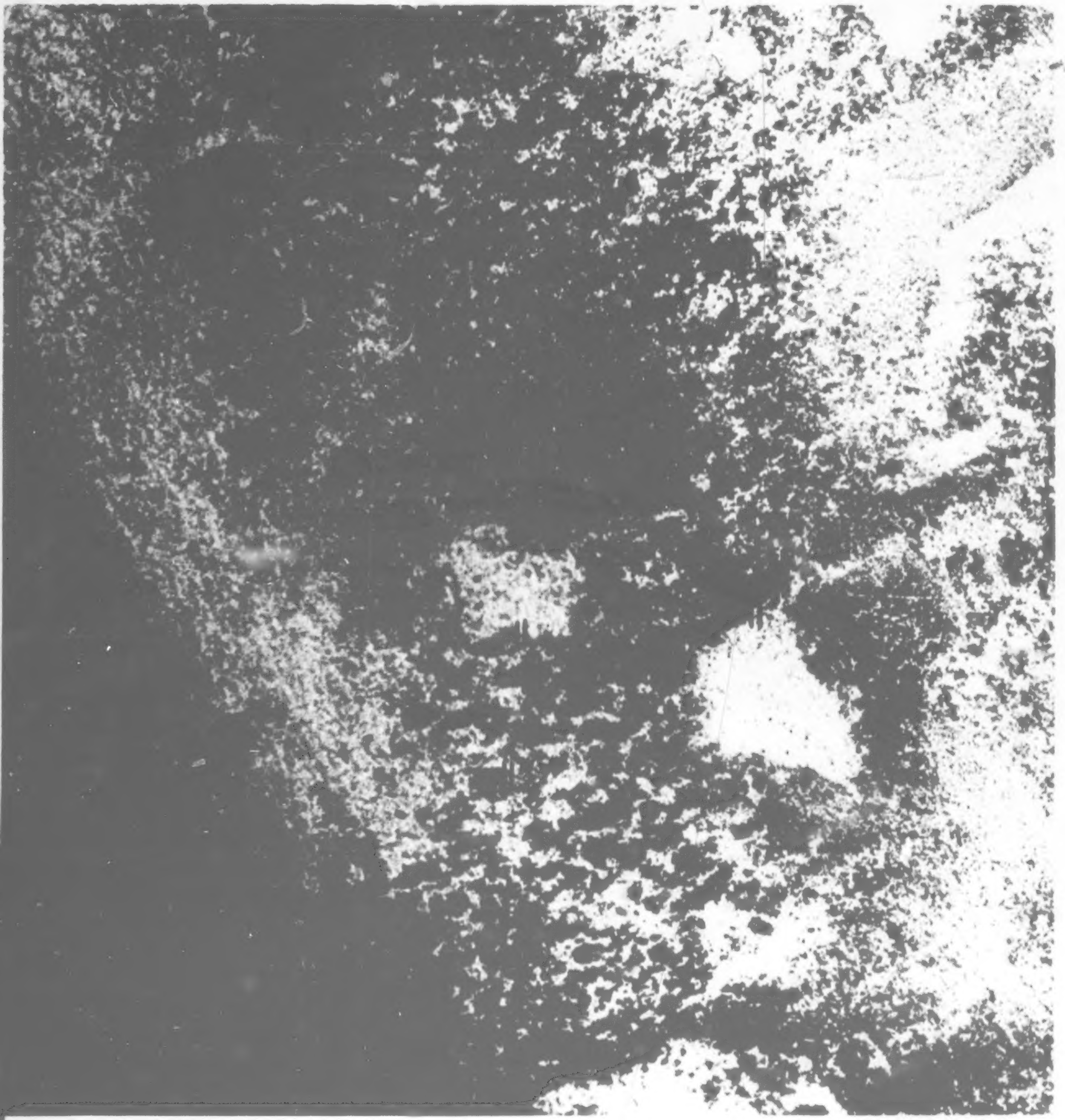

Figure 2. A three times enlargement of a frame acquired over the "Nine Cannon Wreck Site." Anomalous ground features underlined in red. See text for complete explanation.

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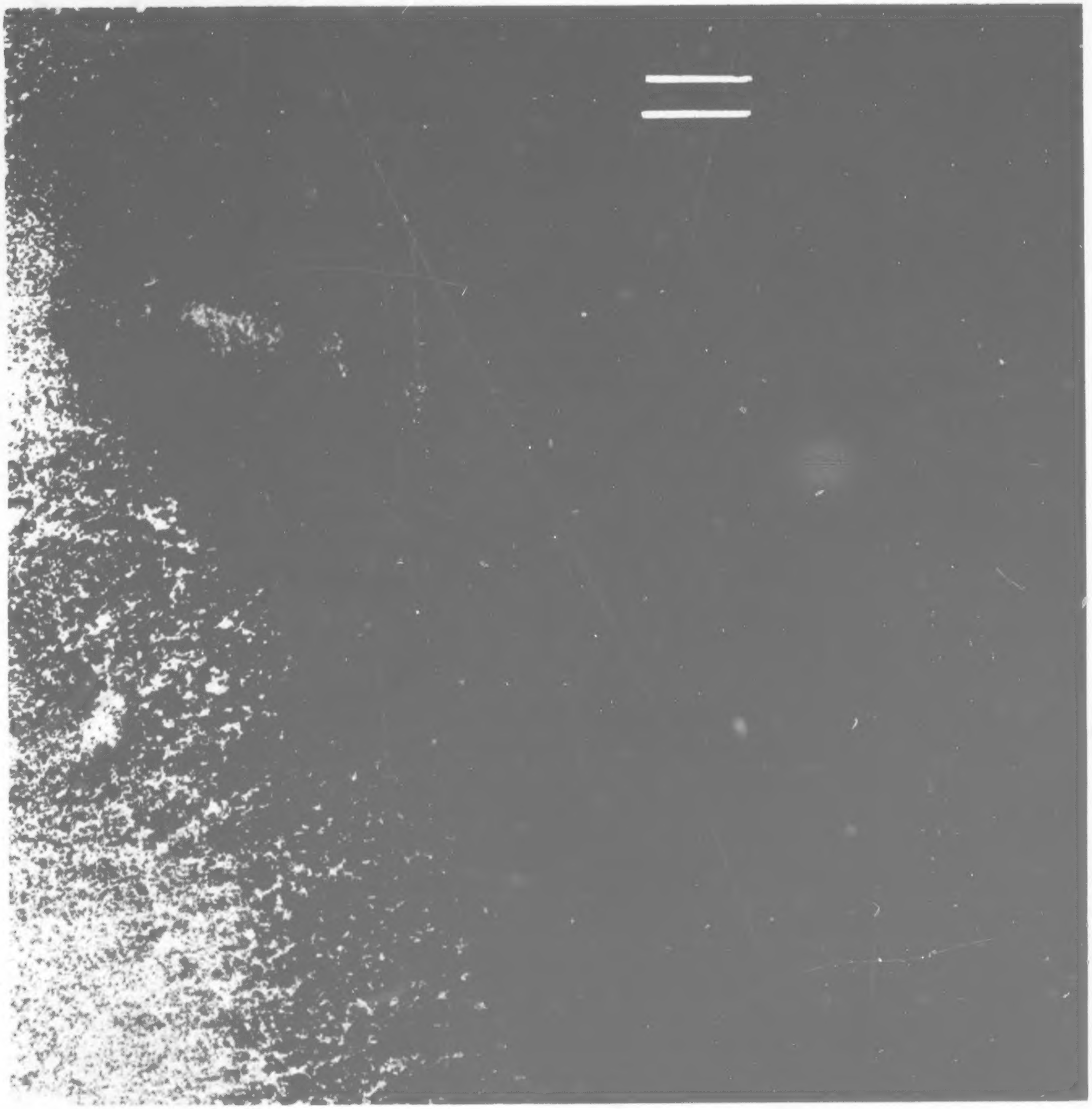

Figure 3. A three times enlargement of a frame acquired over the "Nuestra Senora del Rosario Site." Curvilinear feature outlined in red. See text for complete explanation.

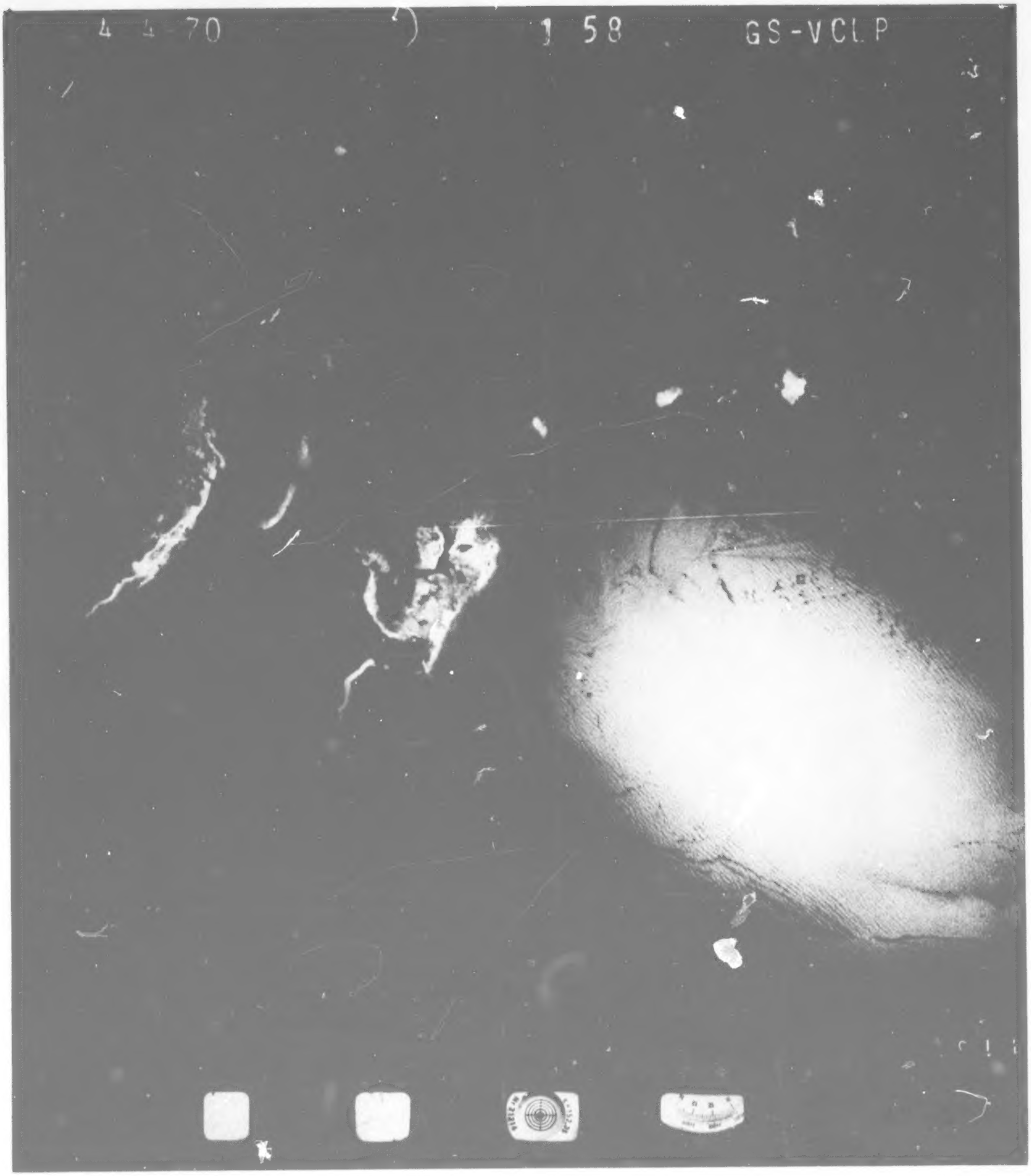

Figure 4. USGS 1:83,000 photography of Fort Jefferson National Monument. The area encompassing the "Nine Cannon Wreck Site" is shown as block 1; the area encompassing the "Nuestra Senora del Rosario Site" is shown as block 2.

MARINE ARCHEOLOGY

Vocabulary - Define the following terms in detail.

Multispectral
Anomaly
1/24000
Magnetometer
Filter
1:76,000

Questions - Answer the following inquiries in detail.

1. What is the historical significance of the Spanish in the Florida Keys?
2. Why is remote sensing unique in the Florida Keys as a technique of discovery?
3. Why is simultaneous photography necessary?
4. What percentage of a treasure find does the state of Florida keep?
5. Discuss the differences in the four types of film.
6. Why is water clarity important?
7. Discuss a typical reef.
8. Why are exacting procedures necessary in archeology?
9. How does a magnetometer function in wreck discoveries?
10. Why are filters important as they relate to water conditons?

Discussion Topics

1. Prepare a discussion on the problems of the Spanish Armada as it relates to the shallowness of the Florida Keys.
2. What factor would weather forecasts play in the disasters of Spanish treasure ships?

THE MAPPING OF MARSH VEGETATION USING AIRCRAFT MULTISPECTRAL SCANNER DATA

Principal Investigator
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NASA Earth Resources Survey Symposium
Houston, Texas - June 1975
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ABSTRACT

A test was conducted to determine if salinity regimes in coastal marshland could be mapped and monitored by the identification and classification of marsh vegetative species from aircraft multispectral scanner data. The data was acquired at 6.1 km (20,000 ft.) on October 2, 1974, over a test area in the coastal marshland of southern Louisiana including fresh, intermediate, brackish and saline zones. The data was classified by vegetational species using a supervised, spectral pattern recognition procedure. Accuracies of training sites ranged from 67% to 96%. Marsh zones based on free soil water salinity were determined from the species classification to demonstrate a practical use for mapping marsh vegetation.

INTRODUCTION

The United States can claim 30 million acres of marsh, or non-forested wetland, among its 26 coastal states and territories (1). The marsh includes such aquatic areas as fresh water lagoons and sloughs, estuaries, and the generally more saline coastal interfaces.

The coastal zone not only offers residence to approximately one-third of the nation's population, but also contains vast marshlands which represent an economically valuable, renewable resource. Non-forested wetland provides breeding grounds for commercial fish, shellfish, and fur-bearing animals. It also provides recreational activities such as boating, hunting and fishing, and represents a natural purification and drainage system for water flowing to the coast from more congested areas. Any environmental change within the marsh may impact the benefits derived from it, and thus monitoring the marsh becomes necessary for proper management.

One method of monitoring the marsh is the recording of marsh vegetation, as any type of vegetation growing in an area is an indicator of its environment. This paper deals with the utilization of multispectral remote-sensing by the modular multiband scanner (MMS) as a means of mapping expanses of marsh vegetation for use in the environmental monitoring of salinity intrusion.

DESCRIPTION OF STUDY AREA

A 72.5 km transect through the marsh of Louisiana, which alone claims seven million acres of marsh, was selected for the study described in this paper (Fig. 1). The study area is a representative sample of the Louisiana marshes, which originated from the old delta of the Mississippi River as it shifted course with time along the coast. The area is of interest because it is believed to be undergoing salt water penetration from the coast due to the introduction of man-made canals (2). Further, the same area is experiencing a reduction of fresh water flow from the Mississippi River and its tributaries

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due to the imposition of levee systems that prevent natural flooding of the marsh (3).

Changes in salinity levels give rise to environmental change, affecting marine productivity. The Louisiana marsh serves as a nursery for such commercially valuable animal life as menhaden, crab, oyster, shrimp, nutria, mink and muskrat, each depending on the status quo of a given salinity range to survive, where the brackish marsh, between fresh and salt water regimes, is the most productive (1). The study area includes a transitional zone of brackish marsh, grading into fresher inland marsh in one direction and more saline coastal marsh in the other.

In a more general sense, the sutdy area may be representative of most marshes, because though geographically dispersed across the continent, the marsh maintains a uniformity in type and succession from Nova Scotia to Mexico, where water is the common factor and sodium chloride is the limiter (4). Thus, such uniformity of marsh suggests a general applicability of the results of this localized study to other areas.

CONCEPT

The establishment of particular vegetative species in the marsh is dependent on such environmental factors as tidal phenomena, soil type, rainfall, temperature, and both horizontal and vertical gradients of soil salinity (5).

Comprehensive studies of the Louisiana coastal marsh vegetation have arranged dominant marsh species into groups based on soil water salinity alone (2, 6). Typical marsh types are shown in Figs. 2-23. The most recent work, premised on the salinity groups mentioned above, has divided the Louisiana marsh into four types: fresh, intermediate, brackish. and saline, each type being characterized by a given soil salinity range and association of plant species (Tab I) (7). Chabreck's 1968 marsh zonation of Louisiana, the work mentioned above, was accomplished by the recording of vegetation types from a helicopter following transect lines approximately 12 km (7.5' in latitude) apart, with interpolation of the salinity zones between the lines (Fig. 24).

The objective of this paper is to demonstrate that the same task of identification of marsh vegetation and the determination of marsh salinity zones can be accomplished by an aircraft multispectral remote-sensor with the advantages of greater efficiency and the accuracy associated with total area coverage. This investigation is preliminary to the classification of satellite multispectral data for marsh salinity zone determination.

EXPERIMENT DESIGN

The area described in this paper represents flight line #3 of the 15 flight-line design set of NASA Mission 287, from which MMS data and color IR imagery were acquired in the Louisiana marsh on October 2, 1974. Associated information for flight line #3 follows:

Aircraft	Ground Speed	Altitude	Time (CST)
NP3A	6.5 km/hr	6.1 km	Start 11:20:00
			Stop 11:26:00

Sensors	Scan Rate
Zeiss	
MMS[1]	12 rev./sec.

Possible training sites, for use in the supervised pattern recognition system of classification, were selected from color IR imagery acquired over the area in 1973, based on variations in texture and color that would lead to sites representative of dominant marsh vegetation species. Expanded chronopaques of the color IR imagery were produced on which the training sites were marked to use as "maps" for the gound truth expedition.

Ground truth of the training sites was accomplished almost exclusively by helicopter July-August 1974, since the marsh was generally inaccessible by car and often even by boat. While the helicopter hovered over a training site located on the chronopaque map, several overhead photographs were taken between 61m to 15m (200' to 50') and observations were recorded regarding the % barren and/or water in the site and the total % vegetation in the site. The percent of each observed species and dead plant material was also noted. Species not immediately identifiable were collected for laboratory study and herbarium mounts.

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[1] The MMS has an instantaneous field of view of 2.5 milliradians, a full scan angle of 100° ± 20° and a scan rate range of 10-100 revolutions/sec.

The field description of each training site was reviewed and the training site rejected for further use in the classification process if it did not represent a dominant marsh species or typical association of species.

The original pulse-code-modulated tape which recorded the MMS Mission 287 data was decommutated and made computer-compatible on the data analysis station (DAS) at the Earth Resources Laboratory at the National Space Technology Laboratory, Bay St. Louis, Mississippi. MMS channels 5, 7, 8 and 10, representing wavelengths .58-.62, .66-.70, .70-.74 and .97-1.06 μm, respectively, were used in the pattern recognition classification (8). Salinity zones were interpreted from the resultant marsh vegetational classification and compared with those derived by Chabreck (7).

RESULTS

The observed composition of each training site used in the classification of the study area is listed in Table II. Usually, one species dominated a training site, with one or more subdominant species occurring in association with the dominant. Some sites included a given percentage of water and/or sediment. The locations of training sites are indicated on the color IR imagery acquired from NASA Mission 287 (Fig. 25).

The marsh vegetation of the study area was classified from the MMS data using water and six different vegetative classes (Fig. 26). The unclassified areas probably represent agricultural fields, barren, and/or urban areas for which no training sites were included. Only the area covered by 90° of the total 120° scan is shown in the classified map.

Classification accuracies of the training sites, a function of class versus class-name percent occurrences, ranged from 68.7% to 96.0%, with an average of 88.2% (Table III).

Salinity zone lines within the study area were defined associations where *Sagittaria falcata*, *Panicum hemitomon*, and *Myrica cerifera* as dominants indicated a fresh zone; *Spartina patens* as a dominant indicated a brackish zone; *Spartina alterniflora* and *Avicennia nitida* as dominants indicated a saline zone; and the transitional area where *Spartina patens* appeared with other fresh marsh vegetative types indicated as intermediate zone (Fig. 27b). The salinity zone delineation derived from this remotely-sensed classification differed from the delineation derived by line-transect method in 1968 (Fig. 27a). The latter indicated a broader area of intermediate zone, but not extending as far south as in the former, and a larger area of saline zone extending more inland.

DISCUSSION

A September-October time frame for data acquisition was chosen based on the fact that the majority of marsh species are mature at that time, many of them flowering in the fall (6). The multispectral signatures of mature plants were assumed they would be more distinct, producing better separation and less misclassification, although this point may not be true in certain cases. Since the data was collected in a north-south direction, a flight time when the sun would be directly overhead was stipulated to minimize the illumination of one side of the flight line more than the other. Ground truth field work for identification of training site vegetation was timed to coincide, at least in the same season, with MMS data acquisition to avoid misrepresentation of training site location and vegetative type input to the pattern recognition system.

Analysis of the processed data led to some interesting observations. At an altitude of 6.1 km, the MMS instantaneous field of view (resolution cell size) is 15 m. Training sites large enough to include at least 25 resolution cells were considered statistically significant samples. Standard deviations of the mean reflected radiation in each channel for a given training site seem to be indirectly proportional to resolution cell size, the multispectral response of a site becoming less integrated and the responses of different elements within a site more discrete with lower altitude and consequent greater resolution, based on this author's experience of MMS data from 3.05 km.

Of a possible 11 channels with a wavelength range of .38 µm to 14 µm, only channels 2, 5, 7, 8, 9 and 10 were able to be decommutated from the original MMS tape. Analysis of the obtained channels indicated that the recorded reflected radiation was not a function of ground elements alone. As the scan angle increased from nadir, so did reflected radiation due to the atmospheric interference associated with longer path length. Data from the shorter wavelength channel 2, .44-.49 µm, seemed most affected by the greater amount of light scattering related to the atmosphere. Therefore, channel 2 data was dropped and the combined signal of channels 5, 7, 8, and 10 improved. Homogeneous training sites were desired, but in an extensive area of uncultivated vegetation, one or more species may grow naturally in association with another. Thus, the multispectral signature of a training site may represent in some cases the integrated response of a mixture. The question of the degree to which a mixture may vary in composition and still be represented by the same signature needs to be addressed, as it probably affected the classification accuracy of this investigation. Similarly, the amount of water tolerated in a marsh training site without producing an unacceptably high standard deviation of the mean reflectivity for a given channel should be studied as it relates to this classification.

In comparing color IR imagery to classified scanner data, more marsh vegetative types could be identified by the MMS data (Fig. 26) than by photo-interpretation of color IR imagery (Fig. 25). The relatively high accuracies of the training site classifications, except for that of the Spartina patens/Cyperus spp. which probably was affected by the presence of water, indicated good separation of the vegetative classes.

Once the remotely-sensed identification of vegetation in the marsh study area was accomplished, delineation of the area into salinity zones depended on definition alone. Chabreck's similar delineation of salinity zones of the same area (Fig. 27a) is the only basis for comparison with the results of this investigation. However, the variable introduced by the two different methods of data acquisition and salinity zone interpretation does not make the comparison direct. Nevertheless, the salinity zones determined by this investigation follow the same trend as those determined by the work mentioned above. Variations between the 1968 determination and the one represented by this investigation may be explained by the natural phenomena of salinity intrusion, fluctuations in rainfall and spring floods that have occurred since the earlier work.

CONCLUSION

Results of this investigation demonstrate that vegetational species can be identified and mapped with a good degree of accuracy over a large area of the Louisiana marsh by using aircraft multispectral scanner data. The same

technique can probably be applied to mapping marsh vegetation in other areas, as well.

This capability can be applied to determine salinity zones within the marsh for monitoring salinity intrusion, a factor influencing the growth and ultimate harvesting of fish, shellfish, and fur-bearing animals for commercial use.

Further, the remote-sensing capability of marsh species identification can be applied to monitor the distribution of one or more plant species as it may affect: (1) navigation, as in the case with the water hyacinth, (2) marine productivity estimates, as in the case with oystergrass, (3) wild life foraging, as in the case with 3-cornered grass, and (4) coastal zone definition.

ACKNOWLEDGEMENTS

I wish to acknowledge the effort ot the Lockheed Electronics Co., Inc., personnel who supported this investigation, particularly those of Chris Gauthier, Wildlife Specialist, and Ron Vaughn, Data Processor. I also wish to extend special thanks to Ronnie Pearson, NASA/ERL mathematician, for his work with atmospheric interference, and Howard Clark, General Electric, for the botanical expertise he contributed to this study.

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TABLE I. MARSH SPECIES ASSOCIATION FOR SALINITY ZONE DEFINITIONS

(from Ref 7)

MARSH ZONE	FREE SOIL WATER SALINITY AVE. (PPT)	MAJOR INDICATOR SPECIES
Fresh	1	MAIDEN CANE (Panicum hemitomon), Hydrocotyl sp., WATER HYACINTH (Eichornia crassipes), PICKEREL WEED, (Pontederia cordata), ALLIGATOR WEED, (Alternanthera philoxeroides), BULLTONGUE (Sagittaria sp.)
Intermediate	3.3	WIREGRASS, (Spartina patens), DEER PEA (Vigna repens), BULL TONGUE WILD MILLET (Echinochloa walteri), BULLWHIP (Scirpus californicus), SAWGRASS (Cladium jamaicense).
Brackish	8.1	WIREGRASS, THREE CORNERED GRASS (Scirpus olneyi), COCO (Scirpus robustus), WIDGEONGRASS (Ruppia maritima)
Saline	15.9	OYSTERGRASS (Spartina alterniflora), Salicornia sp., BLACK RUSH, (Juncus roemerianus), Batis maritima, BLACK MANGROVE Avicennia nitida, SALT-GRASS (Distichlis spicata).

TABLE II. COMPOSITION OF TRAINING SITES FOR LINE 3-2, MISSION 287[a]

Training Site Field Number	Composition
3	*Sagittaria falcata* 40%, *Panicum hemitomon* 40%, *Typha sp.* 5%, *Eleocharis microcarpa* 5%
5	*Spartina patens* 70%, *Cyperus sp*. 10%, *Bacopa monnieri* 5%, water 15%
9	*Myrica cerifera* 40% *Panicum hemitomon* 50%
11	*Spartina patens* 50%, water and sediment 50%
75	*Spartina alterniflora* 80%, water and sediment 20%
78	*Avicennia nitida* 70%, *Spartina alterniflora* 15%, water 10%
178	*Spartina patens* 95%, *Scirpus sp.* 3%
179	*Spartina patens* 90%, water 10%
198, 200-209	water (varying depths and turbidity)

[a]/ determined by field observations July-Aug. 1974

TABLE III. ACCURACY CHECK OF TRAINING SITES FOR MARSH CLASSIFICATION OF FLIGHT LINE 3-2, MX. 287

	CLASS-NAME % OCCURRENCES									
	1	2	3	4	5	6	7	8	9	27
CLASS	3SFPA	11SP	178SP	9MCPA	5SPCY	H_2O	179SP	75SA	78ANSA	UNCLASS.
1 - 3SFPA	91.67	2.63		.44					.22	5.04
2 - 11SP	2.63	89.25	1.97	1.10					1.10	3.95
3 - 178SP		2.80	89.32		.53		1.23			6.13
4 - 9MCPA	.51	.25		95.96						3.28
5 - 5SPCY	.29	2.30	1.01		68.68	3.16	.14			24.43
6 - H_2O						95.25		.56		4.19
7 - 179SP	.26						76.30		.26	23.18
8 - 75SA					.16	.49	1.79	92.67		4.89
9 - 78ANSA		1.79							94.64	3.57

SFPA = *Sagittaria falcata*/*Panicum hemitomon*
SP = *Spartina patens*
MCPA = *Myrica cerifera*/*Panicum hemitomon*
SPCY = *Spartina patens*/*Cyperus sp.*
H_2O = Water
SA = *Spartina alterniflora*
ANSA = *Avicennia nitida*/*Spartina alterniflora*

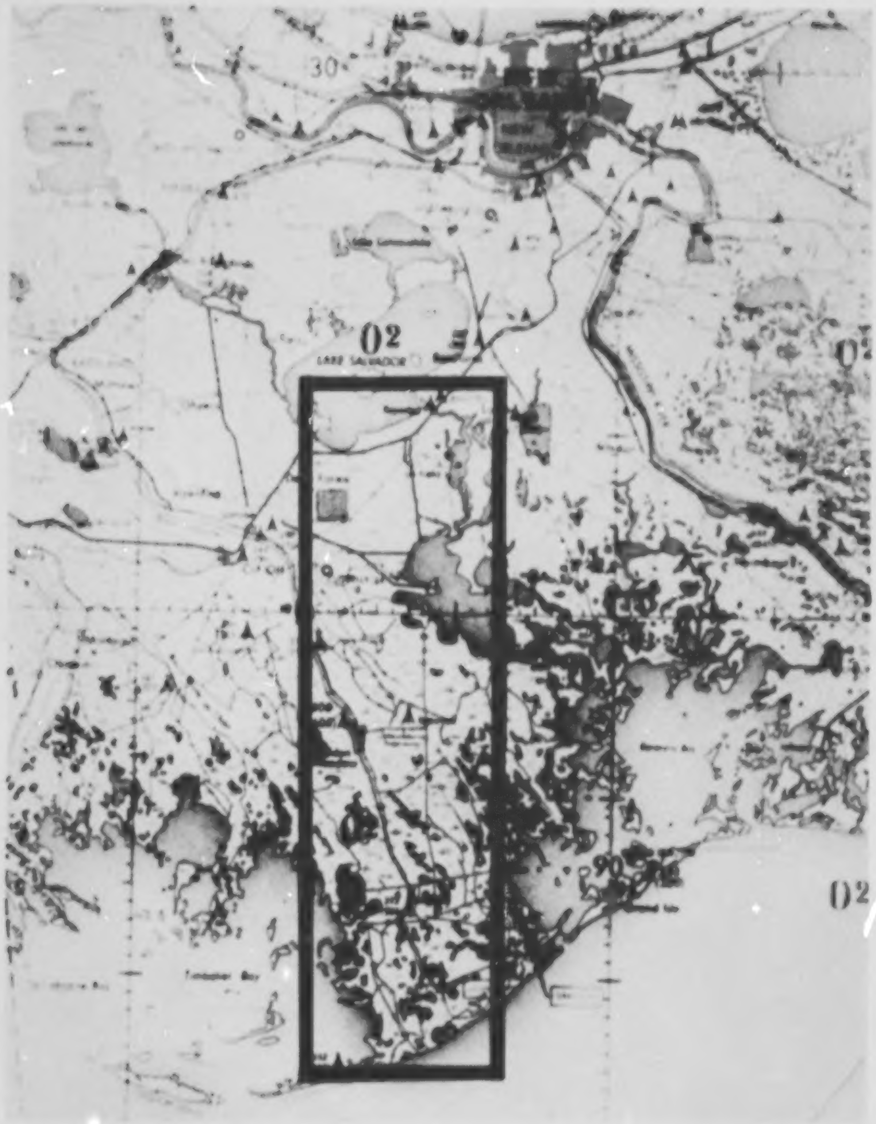
30°
0²
LAKE SALVADOR
0²
0²

Fig. 1 Test site location MMS mission 287 flight line 3-2, Oct. 2, 1974.

Figure 2. Black willow, Salix nigra, commonly borders fresh marsh areas along spoil banks and newly accreted land.

Figure 3. The interface between fresh marsh (left), and cypress swamp (right) indicates an ecotone. Dead standing trees in the marsh represent a changing environment.

Fig. 4. Bulltongue, *Sagittaria falcata*, is a common fresh marsh plant.

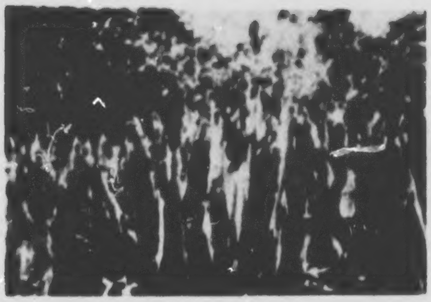

Fig. 5. Low shrubs (background) commonly border spoil banks, giving way to fresh marsh plants such as bulltongue (foreground).

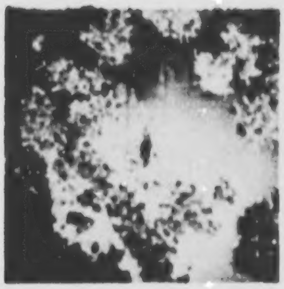

Figure 6. Helicopter view of bulltongue indicates standing water is a common element of fresh marsh.

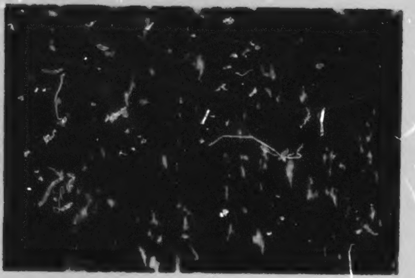

Fig. 7. Cat - tail, Typha latifolia, is a typical marsh species.

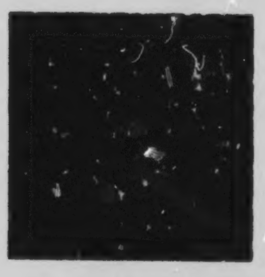

Fig. 8. Helicopter view of maidencane, Panicum hemitomon, dominating the Louisiana fresh marsh.

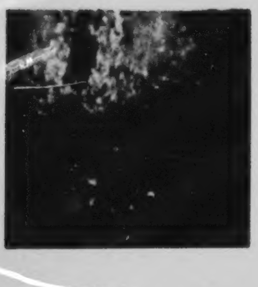

Fig. 9. Helicopter view shows water hyacinth choking waterways bordered by buckbrush, Baccharis halimifolia, a fresh to brackish shrub.

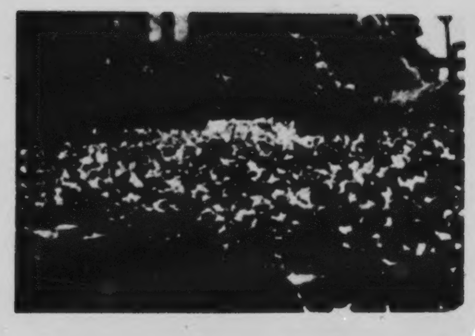

Fig. 10. Water hyacinth, Eichhornia crassipes, forms floating vegetative mats in the fresh marsh.

Fig. 11. Roseau cane, Phragmites communis, is a 2-1/2 to 4 m grass usually found along elevated areas in the fresh marsh.

Fig. 12. Standing roseau cane stalks from the previous growing season are shown at the back slope of a spoil bank, indicated by the growth of wax myrtle, Myrica cerifera, in the fresh marsh.

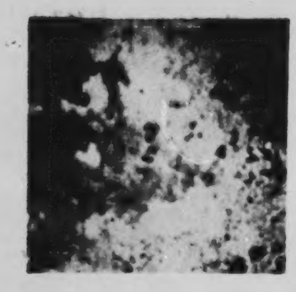

Fig. 13. Helicopter view at 155m shows variation in color and texture pattern produced by the association of buckbrush and roseau cane in the fresh marsh.

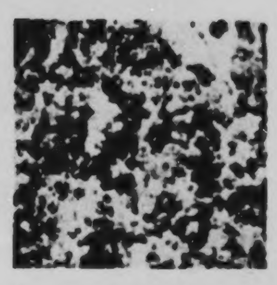

Fig. 14. Helicopter view at 30 m showing dioecious nature of buckbrush where the lighter colored plant is in flower.

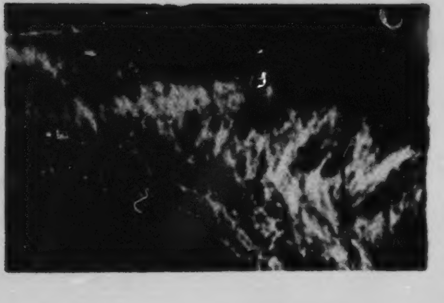

Fig. 15 An association of wiregrass, *Spartina patens*, (foreground) three - cornered grass, *Scirpus olneyi*, and blackrush, *Juncus roemerianus*, indicates a brackish marsh.

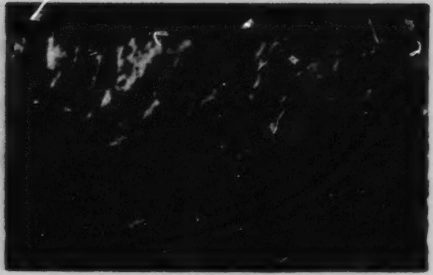

Fig. 16 A mixture of wiregrass and three - cornered grass: wiregrass dominates this area with dispersed areas of three - cornered grass.

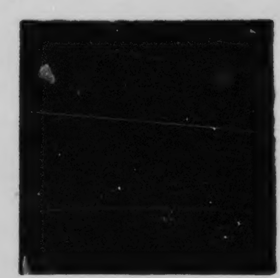

Fig. 17 Helicopter view at 15 m shows homogenous stand of wiregrass.

Fig. 18. Oyster grass, Spartina alterniflora, is a 1-2 m grass dominating the saline marsh.

Fig. 19. Salt grass, Distichlis spicata, a plant 15 to 50 cm, commonly grows in association with the taller oyster grass.

Fig. 20. Helicopter view of homogenous stand of flowering oyster grass found in the saline marsh.

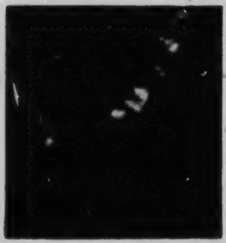

Fig. 21. A mixture of salt grass (foreground) oyster grass (light green area) and wiregrass, is a common saline type association as viewed from 60 m.

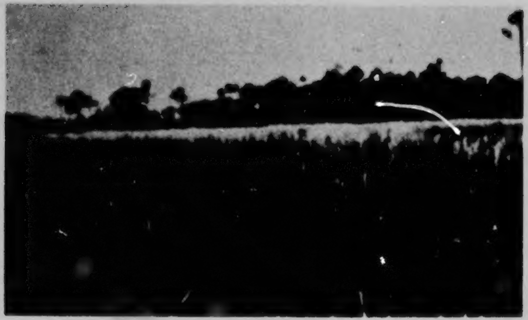

Fig. 22 Extensive blackrush occurs in a brackish to saline area, interfacing an oak-pine chenier background.

Fig. 23 Helicopter view of black mangrove, Avicennia nitida, a 1-2 m shrub growing along the most saline areas of the Louisiana coast.

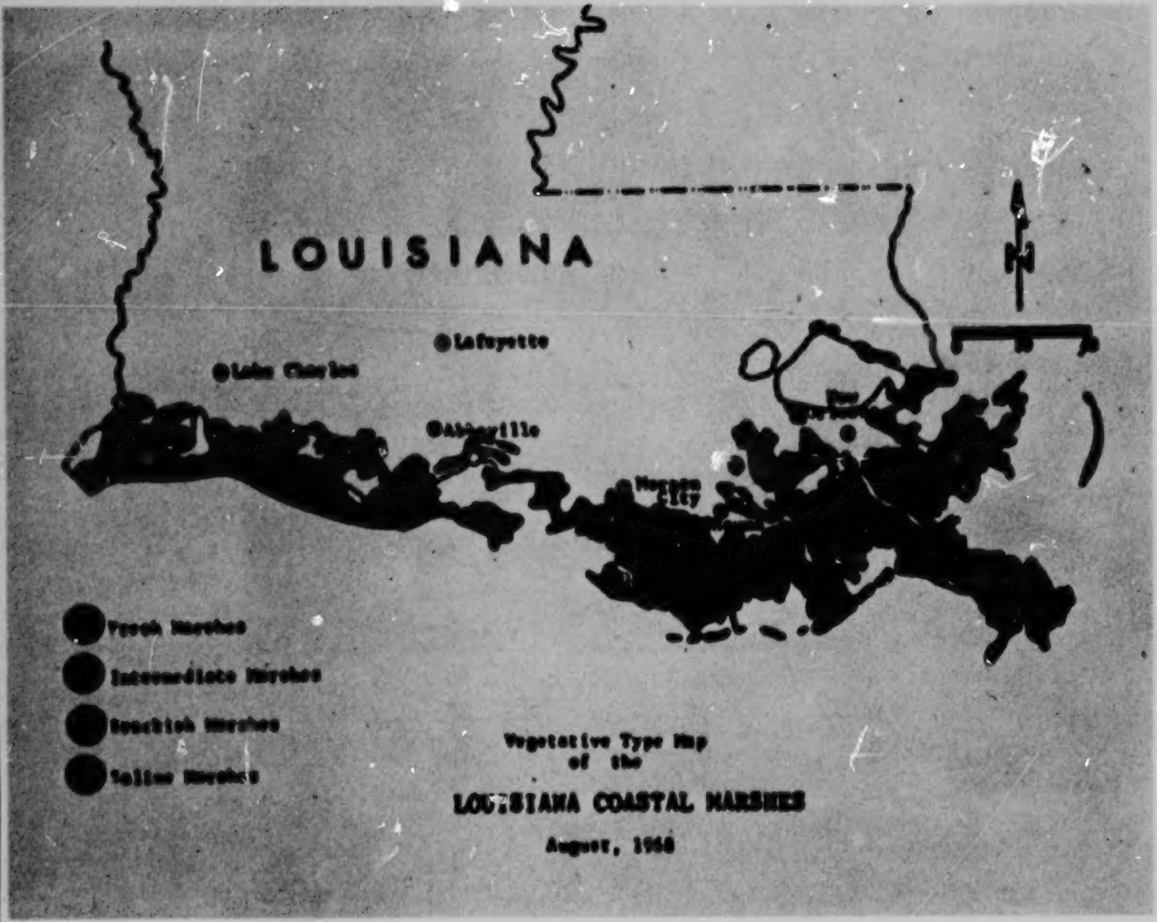
LOUISIANA
Lafayette
Lake Charles
Abbeville
Morgan City
New Orleans
N
Fresh Marshes
Intermediate Marshes
Brackish Marshes
Saline Marshes
Vegetative Type Map
of the
LOUISIANA COASTAL MARSHES
August, 1968

Figure 24.

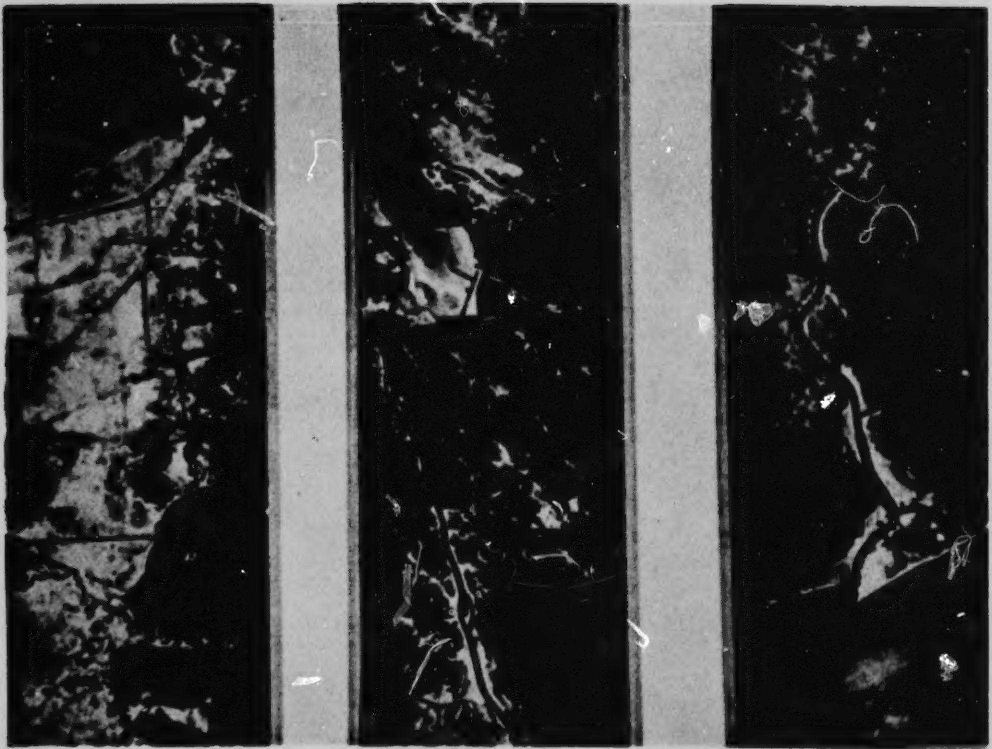

Figure 25. Training site locations on color IR photography of south Louisiana marsh flight line 3, MX 287.

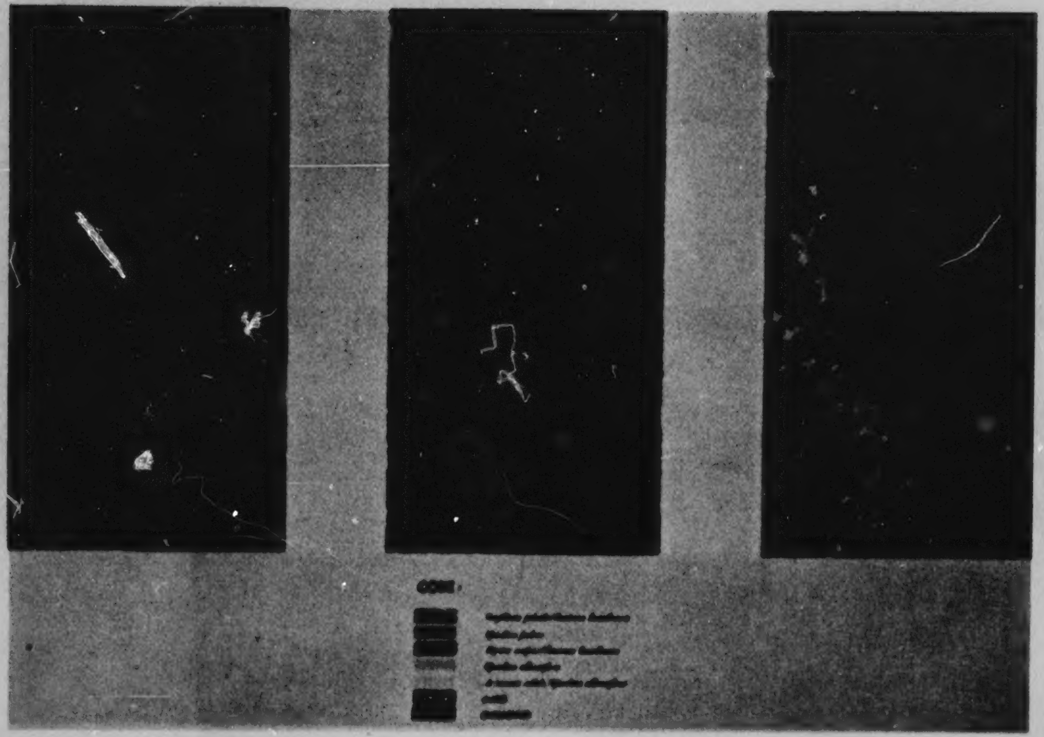

Fig. 26. MMS classification of major species associations of marsh vegetation Oct. 2, 1974.

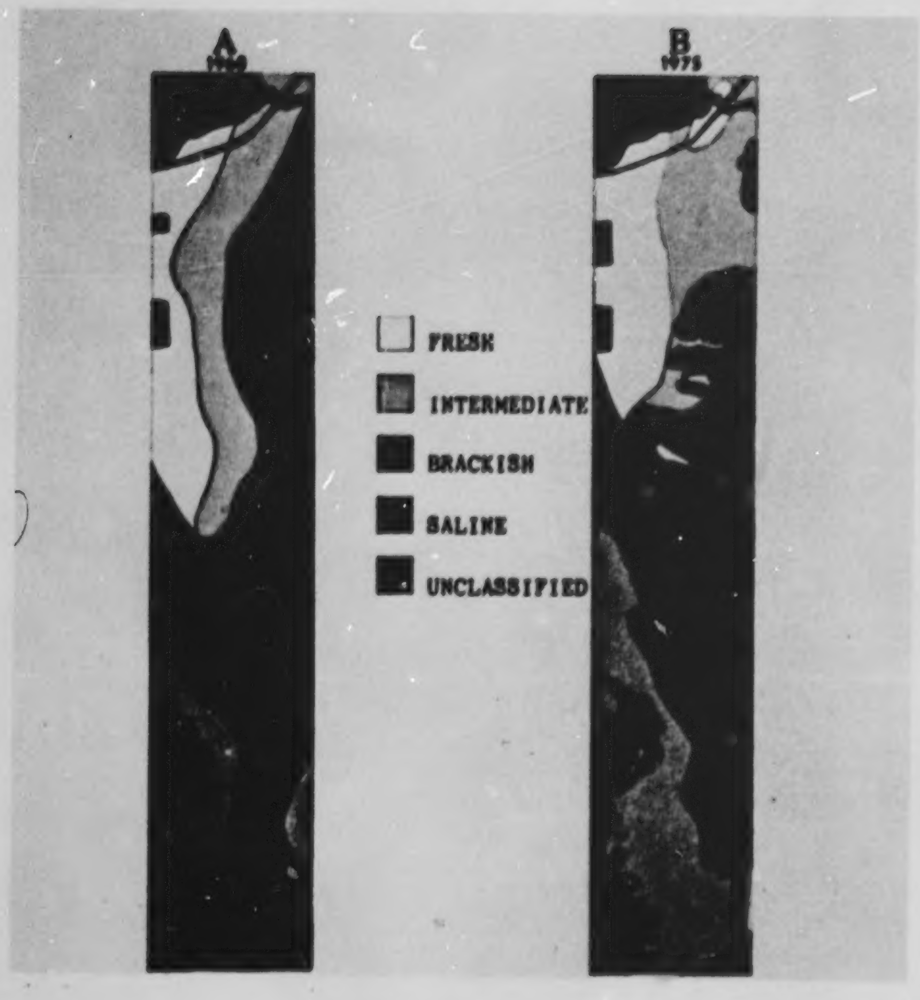
A
B
FRESH
INTERMEDIATE
BRACKISH
SALINE
UNCLASSIFIED

Fig. 27 Thematic maps of marsh salinity zones

A. Marsh zones determined by line-transect method (R. H. Chabreck)

B. Marsh zones determined from multispectral scanner data 20'K

MAPPING MARSH VEGETATION

Vocabulary - Define the following terms in detail.

Salinity
Brackish
Saline
Transect
Color IR
km
Chronopaques
Resolution cell size
Wavelength range
Pattern recognition

Training site
Sagittaria falcata
Panicum hemitomon
Myrica cerifera
Spartina patens
Spartina alterniflora
A vicennia
Homogeneous
Salinity intrusion

Questions - Answer the following inquiries in detail.

1. What is the total land mass of marshland in the United States? What are the physical parameters?
2. Discuss in detail the effects of salinity changes on a marsh environment.
3. What is the overall objective of this research paper?
4. Why were certain species limited to particular salinity zones?
5. Why was the early fall used for data acquisition?
6. How can marsh species identification be applied to monitoring the distribution of plant species?
7. What was the importance of the use of aircraft multispectral scanner data?
8. What differences were apparent in comparing color IR imagery to classified scanner data?
9. What are the two factors in marshlands that are the same from Novia Scotia to Mexico?
10. Why was the Louisiana area selected for study?

Discussion Topics

1. Explain the three phases of mangrove swamp trees development.
2. How do mangrove trees feed and breathe in salt water?

SOLID WASTE AND REMOTE SENSING

Preliminary studies suggest that small-scale aerial remote-sensing records and, in particular, aerial photographs can contribute to regional solid-waste management and planning.

Principal Investigators
DONALD GAROFALO Earth Satellite Corporation
FRANK J. WOBBER Earth Satellite Corporation

Photogrammetric Engineering,
January 1974, Vol. 40 No. 1

ABSTRACT

In order to implement practical solid-waste planning and management at the regional level, data acquisition systems which are unrestricted by jurisdictional boundaries are needed. High-altitude aircraft remote sensing provides a regional working data base and information including waste distributions, waste characteristics, and quantities. Solid-waste quantities for a given area can be estimated from high-altitude aircraft photographs providing collateral statistics such as average amount of waste generated by a waste source unit, e.g., residential dwellings, commercial or industrial facilities or by population are available. Interpretation of high-altitude aircraft remote-sensing records provides essential data for solid-waste planners including the location of waste disposal sites and facilites and contributes toward selecting the most suitable disposal method or methods for a given region.

INTRODUCTION

Increasing population growth has accelerated the generation of solid wastes. At the same time available land suitable for proper waste disposal has decreased, and the search has begun for more efficient waste disposal methods. Concern for environmental degradtion has increased the need for a better understanding of disposal site suitability. The collection, transportation, and disposal of solid wastes increasingly crosses jurisdictional boundaries and suggests regional solutions to solid waste problems must be found. To approach this problem at the regional level, data are needed related to: (1) the quantity of solid wastes generated, (2) the characteristics of those wastes, and (3) satisfactory disposal sites/methods.

That remote sensing can provide useful solid-waste management and planning data at the regional level is suggested by the authors' studies. Natural color and color-infrared aerial photography at scales from 1:12,000 to 1:120,000 were analyzed and applied to: (1) estimates of waste characteristics and quantities, (2) waste disposal site selection and utilization, (3) waste collection and transportation, (4) environmental impact of on-site and off-site disposal, and (5) location and identification of waste generating sources.

This paper examines existing techniques for acquiring statistical data for solid-waste management and addresses remote-sensing

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Presented at the Annual Convention of the American Society of Photogrammetry in Washington, D.C., March 1973.

applications to estimates of solid-waste characteristics, distributions and quantities in the Tampa, Florida, area. It is anticipated that this preliminary work will be extended under NASA'S ERTS-B program.

SOLID-WASTE ESTIMATION TECHNIQUES

Accurate data on quantities of solid waste generated for the nation or regions are often unavailable despite the use of national averages, field surveys, prediction models and waste multipliers. For purposes of this preliminary report, each technique will be addressed separately with a view toward selecting suitable techniques for incorporation into a solid-waste quantity prediction and estimation system, which utilizes remote-sensing data.

NATIONAL AVERAGE TECHNIQUE

It has been estimated that the national average of waste generated per capita per day is 4.56 pounds (Table 1)+. Within urban areas the average is 5.92 pounds/capita/day, whereas in rural areas the average is 3.70 pounds/capita/day. Applying factors in Table 1 to the Tampa, Florida, area, a solid-waste characteristic and quantity profile for Tampa (based on present population of 277,767) would approximate the data presented in Table 2.

FIELD SURVEY TECHNIQUE

A 1968 national survey[1] of 6,259 communities (for an estimated 1967 population of 92,539,674 persons) was completed to determine community solid-waste practices in the United States. The nine regions of the Department of Health, Education and Welfare (including Region IV composed of Florida, Alabama, Georgia, Mississippi, South Carolina and Tennessee) were analyzed.

Measured or estimated quantities of community solid wastes collected annually were studied. Waste categories for which information was gathered included: (1) household, (2) commercial, (3) combined household and commercial, (4) industrial, (5) agricultural, (6) institutional, (7) demolition and construction, (8) street and alley, (9) tree and landscape, (10) park and beach, (11) catch basin, and (12) sewage treatment plant solids and pumping station cleanings. Waste quantities computed (Table 3) using field survey techniques vary greatly by region due to variables including: (1) the size of the population sampled per region; and (2) the physical and cultural characteristics of the regions themselves. State value judgements assigned to data quality provided a further indication as to why discrepancies occurred. Only 6.3 percent of the states reported that data was of good quality, 37.5 percent reported it to be of fair quality, and 56.2 percent reported it to be of poor quality. Based on the 8.3 percent of Florida's population that was surveyed, and comparing Region IV data for Tampa with national data, Table 4 demonstrates the complexity of predicting accurate solid wastes quantities for comparing gross national averages of solid wastes with relatively individualized regional waste quantities.

Some local, highly individualized survey studies have been completed by the Environmental Protection Agency's Bureau of Solid Waste Management. One of these studies[2] investigates quantities of solid waste generated in a residential low-income area of Cincinnati, Ohio. This report states that variations in the generation of solid wastes make it extremely difficult to predict quantities that can be expected from a dwelling within a low-income residential neighborhood. Influencing factors include climate, season, socioeconomic level, and dweller density. Although this study concluded (among other things) that the total number of occupants, not the dwelling type determined the total quantity of solid waste generated, this result is expected in low-income residential areas, due to overcrowding, but would not necessarily be true for other residential areas.

+ This figure represents the total given in Table 1 minus the combined household/commercial waste category. Household and commercial wastes are represented in separate categories.

PREDICTION MODELS

A variety of prediction models for estimating waste quantity and characteristics exist. A prediction model[3] developed by the URS Research Company for the federal solid-waste management program "estimates and predicts on the basis of knowledge of materials and quantities before they become part of the solid waste stream, together with an understanding of the process by which materials become solid waste." This model relies on Bureau of Census and other data for predicting consumption habits in residential areas. Besides data on the consumption habits within a community, however models must rely on information including: (1) population, (2) population density, (3) average size of household, (4) distribution of income, (5) number, size and type of establishments (wholesale and retail trade, selected services, manufacturers, mineral industries, and agriculture). Using the model, waste characteristics as well as quantities may then be estimated for a community.

WASTE MULTIPLIERS

A waste multiplier is a numerical estimation of the average quantity of waste generated by a waste source, resident or employee per unit of time. One report lists a two-step approach for estimating waste quantities using waste multipliers[4]: (1) waste source units are expressed either as number of units, or by level of activity represented either by employment or local use and, (2) quantities of solid wastes are calculated as the product of the waste multiplier and source units. Waste multipliers can be developed for residential, commercial, non-manufacturing and public agencies, industrial, and agricultural sources of wastes. For example, a sample survey was completed in Santa Clara County, California, in order to develop waste multipliers and, finally, to compute the average quantities of waste generated for each waste source. Waste multipliers are summarized in Table 5.

To determine the numerical correlation between solid waste quantity data generated by waste multipliers, national waste averages and direct survey, Santa Clara County waste multipliers were applied to Tampa, Florida. Climatic and broad population similarities made use of California statistics reasonable for this purpose. Table 6 reveals obvious discrepancies between waste quantities estimated using different methods. National waste averages, direct regional survey, and waste multipliers all yield different answers for the same area. Waste multipliers which pertain specifically to Santa Clara County, California, upon application to Tampa, Florida, or to any other area would yield more detailed information on waste characteristics for specific industries than previously cited methods. Waste multipliers, of course are developed from a direct analysis of waste generated by specific types of industry.

ROLE OF REMOTE SENSING

Urban land-use studies using high-altitude aircraft photographs are actively being conducted by several federal agencies, but they have not been applied to solid-waste problems. With 1:120,000 scale photographs and a 9 x 9-inch photo format, approximately 325 square miles of the earth's surface may be inventoried in a single frame. Such aerial photographs can be used to compute the quantities of waste generated in a given area. Wastes have been traditionally grouped into general categories which correspond to: (1) household, (2) commercial, (3) industrial, and (4) agricultural refuse categories. Information on the areal size of each of the refuse categories and their spatial distribution can be easily extracted by experienced analysts from high-altitude aerial photographs. Detailed information within these categories can be obtained. For example, it is possible to separate single-family from multiple-family dwellings, and to distinguish between low- and high-income residential areas. In agricultural areas, crop types may be identified; within industrial areas, specific types of industry can often be identified.

Because solid-waste collection, transportation and disposal is now a regional problem, high-altitude aerial photographs (which cross the restrictions imposed by jurisdictional boundaries) in effect provides a regional working data base.

A special advantage of small-scale, remote-sensing records is that they permit a rapid assessment of the spatial distribution of each refuse category. Little difficulty has been encountered in identifying refuse (solid waste) categories in the Tampa, Florida, test area, or in describing the general characteristics which are associated with each category.

A primary difficulty has been the unavailability of accurate waste quantity data. Considerable effort has been directed to describing present techniques used for estimating waste quantities, and to select the best method for incorporation into a remote-sensing/solid-waste quantity estimation model. National waste averages, direct survey techniques, and waste multipliers are largely based on unit weight or volume generated per resident or per employee. Waste multipliers can also be adapted to waste sources, i.e., can be used to estimate quantities of waste generated by, e.g., single family or multiple family dwellings or agricultural wastes based on field acreage.

Waste multipliers which are based on some form of spot sampling-survey can best be incorporated into a solid-waste quantity estimation/remote-sensing system. Additional surveys such as the one completed for Santa Clara County, California, should be conducted in order to establish meaningful regional, rather than national, waste multipliers. This will facilitate solid waste studies using small-scale imagery.

ESTIMATES OF WASTE QUANTITIES IN TAMPA, FLORIDA

Using high-altitude 1:120,000-scale color-infrared photographs (Figure 1), the waste characteristics, distributions, and quantities for Tampa, Florida, were computed. Waste multipliers were applied to the study area experimentally to test a procedure for future applications of remote sensing to solid-waste quantity estimation. Tampa was separated into ten solid waste source areas (Figure 2) using the 1:120,000 scale photographs. An inventory of the number of buildings within each source area was then completed. In order to simplify computations, an 18-section grid was added to the photograph, and building tabulations were made for each grid (Table 7). Based on the building type and average occupance per unit (1970 Bureau of Census data for Tampa), the number of residents per dwelling and employees per industry have been estimated. Existing waste multipliers were then applied to these figures with the results listed in Table 8.

Although industry subcategories were not singled out for individual computation (principally due to the resolution constraints of the imagery), some types of industrial activity (refining, mining, storage, etc.) could be identified; in conjunction with complementary 1:60,000-scale photographs, detailed waste quantity estimates within industrial areas could be made. (Large-scale photographs will also be tested to estimate floor space and hence estimated number of employees for many industries.)

Agricultural wastes for Tampa were negligible. The Santa Clara study, however, did develop waste multipliers for agriculture and these could easily be developed for other regional areas. (For example, waste multipliers for vineyards and orchards were developed.)

Open space and public recreation area size was calculated, but information on area visitation was necessary in order to estimate waste quantities. Experimental computations to extract these data will be conducted at a later date.

A study by the Environmental Protection

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Agency indicates that wastes generated at swimming beaches, picnic areas, and observation sites vary from .04 to .93 pounds/visitor/day.[5] Considering such variability, recreational waste multipliers based on area estimates from small-scale aerial photographs would be subject to errors. It is judged that high-altitude aerial photographs must be supplemented by large-scale aerial or field observations to ensure accurate recreational waste estimates. (Large-scale photographs can serve, for example, to estimate visitors based on number of cars in parking areas. Light-aircraft observation could also serve as a visitor sampling method.)

Demolition and construction within the city limits of Tampa was negligible. Large-scale building operations on the outskirts of the city could be easily identified on the 1:120,000-scale color-infrared photographs. Although waste multipliers were developed in the Santa Clara study for this waste category, they are based on number of pounds generated per construction or demolition worker and cannot be used to estimate waste quantity based on the size of the construction or demolition project. The use of supplementary large scale photography is required.

Figure 3 shows urban expansion in Tampa. New urban and industrial development add to the solid waste stream, and occupy land suitable for waste disposal. Comparative 1:120,000-scale aerial photographic coverage has proven useful for identifying changes within waste generating source areas, new development (urban or industrial), the replacement of one category of wastes with another (e.g., residential for agricultural) and discriminating the direction of growth of waste source areas. Changing waste quantities, characteristics, and distrubutions may, therefore, also be estimated. This is essential information for implementing solid waste planning programs (including budgeting) at the regional level.

A variety of other experimental applications of remote sensing to solid waste management problems are being tested. Selected applications are listed in Table 9.

SUMMARY AND CONCLUSIONS

This paper reports on the early results of a research program to explore the utility of aerial remote sensing techniques for solid-waste management and planning. The results obtained to date are encouraging but require additional testing in cooperation with solid-waste management groups.

Preliminary testing suggests that small-scale aerial remote-sensing records, and in particular, aerial photographs can play an important role in regional solid-waste management and planning. A principal contribution of remote sensing is determining the spatial distribution of waste producers (categories of waste generating sources). Computation of regional waste quantities from remote-sensing records can fill existing data gaps. Estimates of solid-waste quantities within waste categories can be made given suitable solid-waste multipliers. Multipliers having sufficient detail for high-altitude surveys can be developed nationally through selective spot sampling (field) surveys. Once developed, waste multipliers used in conjunction with data derived from remote sensing can be used to monitor changes in solid-waste quantities at the regional level.

Existing methods for estimating urban waste quantities based mainly upon population statistics apparently vary no more widely than regional statistics acquired using more rapid (and probably less costly) aerial remote-sensing techniques. Satisfactory results can be obtained despite occasional difficulties, e.g., computing recreational or demolition waste quantities. Although primary emphasis has been given to testing methods for determining waste distributions, characteristics and quantities in Tampa, Florida, initial research by the authors suggests that other applications of remote-sensing technology to solid-waste problems appear feasible. These studies will be reported in detail at a later date. A variety of interrelated parameters related to solid-waste site selection and site suitability judgements must be analyzed in planning and managing a regional solid-waste program. Remote sensing can be used to gather a large quantity of the necessary data in a rapid manner and, at the same time, demonstrate important spatial relationships in a single viable format.

REFERENCES

1. Preliminary Data Analysis; 1968 National Survey of Community Solid Waste Practices: U.S. Department of Health, Education, and Welfare; Muhich, Klee, Britton. (483 pp.)

2. Residential Solid Waste Generated in Low-Income Areas; SW-83ts; by George R. Davidson, Jr.; U.S. Environmental Protection Agency, 1972; (14 pp.)

3. Methods of Predicting Solid Waste Characteristics; SW-23c; U.S. Environmental Protection Agency, 1971. (28 pp.)

4. Comprehensive Studies of Solid Waste Management; Second Annual Report; SW-3rg; U.S. Department of Health, Education and Welfare; Public Health Service; Bureau of Solid Waste Management, 1970. (245 pp.)

5. Solid Waste Management in Recreational Forest Areas; SW-16ts; by Charles S. Spooner; U.S. Environmental Protection Agency, Solid Waste Management Office, 1971. (96 pp.)

TABLE 1. AVERAGE SOLID WASTE GENERATED (WASTE FACTORS) BY WASTE CATEGORY

(Pounds/Capita/Day)

Solid Wastes	Urban Waste Factors	Rural Waste Factors	National Waste Factors
Household	1.91	1.67*	1.91
Commercial	0.92	0.30*	0.91
Combined	2.40	3.28	2.64
Industrial	1.40	0.94	1.40
Demolition, Construction	0.47	0.07*	0.47
Street and Alley	0.19	0.01	0.19
Miscellaneous	1.03	.81	0.97
Totals	8.32	7.08	7.20

*Determined through average of estimated and measured waste. Source: Preliminary Data Analysis; 1968 National Survey of Community Solid Waste Practices. U.S. Department of Health, Education and Welfare.

TABLE 2. ESTIMATED SOLID-WASTE QUANTITIES FOR TAMPA, FLORIDA (TONS/DAY) BASED ON NATIONAL AVERAGES APPLIED TO TAMPA'S POPULATION (277,767)

	TAMPA, FLORIDA SOLID WASTE ESTIMATE	
Solid Waste Category	Based on Urban Waste Factors	Based on National Waste Factors
Household	265	265
Commercial	128	128
Combined	333	366
Industrial	194	194
Demolition, Construction	65	65
Street and Alley	26	26
Miscellaneous	143	135
Total	1154 (421,210 Tons/Yr.)	1179 (431,000 Tons/Yr.)

Waste Factors Adopted from 1968 National Survey of Community Solid-Waste Practices Preliminary Report.

TABLE 3. ANNUAL MEASURED MEAN TONS OF SOLID WASTE/1000 POPULATION (REGION IV INCLUDES FLORIDA)

	National	Region I	Region II	Region III	Region IV	Region V
Household Refuse	350.76	339.93	372.02	151.96	259.80	239.65
Commercial Refuse	167.78	148.11	159.46	184.29	120.84	284.02
Comm/Household	482.04	1,685.75	425.92	552.18	520.27	379.69
Industrial	256.89	50.74	171.87	19.08	21.60	*
Agricultural	*	*	*	*	*	*
Institutional	41.70	*	145.91	*	21.88	*
Demolition/ Construction	87.85	377,25	67.90	*	*	*
Street & Alley Cleanings	35.09	73.48	37.54	21.38	*	3.710
Tree & Landscaping Refuse	3,38	128.00	2.37	*	*	*
Park & Beach Refuse	.988	*	.167	*	*	2.84
Catch Basin Refuse	24.68	*	2.15	*	*	*
Sewage Treatment Plant	110.83	*	47.28	20.98	*	141.15

* Insufficient Data: only estimates available.

Region I - Conn., Me., Mass., N.H., R.I., Vermont,
Region II - Delaware, N.J., N.Y., Penn.,
Region III - Kentucky, Md., N.C., Va., W. Va., D.C., Virgin Islands,
Region IV - Ala., Fla., Ga., Miss., S.C., Tenn.,
Region V - Ill., Ind., Mich., Ohio, Wisc.

Source: Preliminary Data Analysis; 1968 National Survey of Community Solid Waste Practices by Muhich, Klee and Britton for U.S. Dept. of HEW, Public Health Services; 1968, 483 pp.

TABLE 4. MEAN ANNUAL TONS OF SOLID WASTE FOR TAMPA, FLORIDA

Table based on a field survey technique with averages applied to Tampa's population (277,767)

Type of Refuse	Based on National Survey Data	Based on Region IV Data
Household Refuse	97,000	71,965
Commercial Refuse	47,000	33,473
Comm./Household	133,000	144,000
Industrial	71,000	5,983[2]
Demolition/Construction	24,000	Insufficient Data
Street and Alley Cleanings	9,500	Insufficient Data
Tree and Landscape	833	Insufficient Data
Park and Beach	250	Insufficient Data
Catch Basin	6,500	Insufficient Data
Sewage Treatment Plant	30,600	Insufficient Data
Agricultural	Insufficient Data	Insufficient Data
Institutional	11,400	5,983
Grand Total	431,000	261,519[3]

1 These quantities were computed based on measured mean tons of waste generated per thousand population surveyed for each category as listed in the Preliminary Data Analysis of the 1968 National Survey of Community Solid Waste Practices.

2 The large variance between this figure and the National figure could be the result of the difference in sample size between the two. Although 2,697 communities were sampled at the National level, only 51 were sampled in Region IV for this category of wastes.

3 A possible cause of statistical differences between Region IV and National Survey Data is the lack of data ("insufficient data") for some refuse-types.

TABLE 5. WASTE MULTIPLIERS

Developed for Santa Clara County, California

Residential	
Single Family Dwelling	1.43 tons/dwelling/year
Multiple Family Dwelling	0.66 tons/dwelling/year
Commercial and Public Facilities	3.81 tons/employee/year
Demolition and Construction	41.3 tons/employee/year
Industrial	
Ordnance and Accessories	0.658 tons/employee/year
Canning and Preserving	5.565 tons/employee/year
Other Food Processing	4.816 tons/employee/year
Tobacco	2.493 tons/employee/year
Textiles	0.525 tons/employee/year
Apparel	0.525 tons/employee/year
Lumber and Wood Products	21.688 tons/employee/year
Furniture and Fixtures	20.155 tons/employee/year
Paper and Allied Products	12.538 tons/employee/year
Printing, Publishing, Allied	13.202 tons/employee/year
Chemicals and Allied	8.210 tons/employee/year
Petroleum Refining	Omitted
Rubber and Plastics	1.548 tons/employee/year
Leather	2.493 tons/employee/year
Stone, Clay, Glass, Concrete	18.114 tons/employee/year
Primary Metals	6.730 tons/employee/year
Fabricated Metal Products	6.730 tons/employee/year
Nonelectrical Machinery	4.182 tons/employee/year
Electrical Machinery	2.978 tons/employee/year
Transportation Equipment	3.393 tons/employee/year
Instruments	2.517 tons/employee/year
Miscellaneous Manufacturing	2.403 tons/employee/year

SOURCE: Comprehensive Studies of Solid Waste Management; Second Annual Report; U.S. Dept. of H.E.W. Bureau of Solid Waste Management, 1970.

TABLE 6. COMPARISON OF SOLID-WASTE QUANTITY DATA GENERATED USING NATIONAL AVERAGE ESTIMATES, REGIONAL SURVEY AND WASTE MULTIPLIER TECHNIQUES AS APPLIED TO TAMPA, FLORIDA

(TONS/YEAR)

Waste Source	National Average Estimates	Direct Survey Region IV (Measure)	Waste Multipliers (Santa Clara Study)
Single Family Dwelling	97,000[a]	72,000[e]	107,250[i]
Multiple Family Dwelling			15,000[j]
Total Household (includes household fraction of combined household/ commercial wastes)	190,000[b]	172,000[f]	122,250
Commercial and Public Facilities (includes commercial fraction of combined household/ commercial wastes)	87,000[c]	76,000[g]	190,000[k]
Industrial	71,000[d]	24,000[h]	114,000[l]
Canning and Preserving	*	*	25,000
Other Food Processing	*	*	
Tobacco	*	*	4,300
Printing, Publishing Allied	*	*	13,000
Chemicals and Allied	*	*	17,000
Stone, Clay, Glass, Concrete	*	*	24,000
Fabricated Metals	*	*	15,000
Miscellaneous Manufacturing	*	*	15,500
Grand Total	348,000	272,000	426,250

[a] Based on National Average for Household Wastes at 1.91 pounds/capita/day and Tampa population of 277,767.

[b] Estimated 70% of combined household/commercial wastes as household.

[c] Estimated 30% of combined household/commercial wastes as commercial.

[d] Based on National Average for Industrial Wastes at 1.40 pounds/capita/day.

* No data Available.

[e] Based on Region IV Average for Household Wastes at 1.41 pounds/capita/day.

[f] Estimated 70% of Region IV combined household/commercial wastes as household.

[g] Estimated 30% of Region IV combined household/commercial wastes as commercial.

[h] Insufficient data was available for measured quantities. Estimated quantities from Region IV survey were used.

[i] Based on waste multiplier of 1.43 tons/dwelling/year for single family dwellings.

[j] Based on waste multiplier of 0.66 tons/dwelling/year for multiple family dwellings.

[k] Retail, wholesale, selected services, banks, hospitals and city government at 50,000 employees and 3.81 tons/employee/year.

[l] Based on waste multipliers in Table 5.

TABLE 7. NUMBER OF BUILDINGS AND TOTAL LAND AREA FOR EACH WASTE CATEGORY IN TAMPA, FLORIDA

	GRID NUMBER																		*Total Number of Bldg.*	*Total Number of Sq. Mi.*
Waste Category	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
Industrial Wastes	0	9	0	0	0	0	50	0	0	20	20	10	0	7	300	50	50	20	543	11
Commercial Wastes	250	350	250	150	350	350	500	650	350	250	350	650	150	0	700	0	150	150	5700	12
Comm. Industrial Wastes	0	0	0	0	0	10	100	0	50	50	100	50	0	0	150	50	20	50	630	4
Residential Single Family (High Density) Wastes	1000	1500	1000	2000	0	1500	1500	1000	1000	1000	1500	1000	1500	0	1000	1000	2000	2000	21500	6
Residential Single Family (Low Density) Wastes	2500	3000	3500	4000	3000	4000	2000	5000	3000	5000	4000	5000	1000	0	3000	0	3000	2000	53000	27
Residential Multi Family Wastes	0	10	0	2	0	0	5	20	20	10	0	20	10	0	10	0	10	20	147	4
Open Space Improved Wastes, Sq. Mi.	0.1	1.5	0.5	0.5	0.1	2.5	2.4	2.0	0.1	0.1	2.0	1.0	0.1	0.3	0.5	0.1	0.1	0.1	N/A	14
Open Space Unimproved Wastes, Sq. Mi.	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0.1	0	N/A	2
Agricultural Wastes, Sq. Mi.	0	0.10	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A	1
Public Recreational Wastes	0	5	4	0	0	5	5	10	0	0	0	10	1	0	5	0	2	5	53	4
Total City of Tampa																			81573	85

TABLE 8. ESTIMATION OF SOLID-WASTE QUANTITIES IN TAMPA, FLORIDA USING REMOTE-SENSING METHODS AND SOLID-WASTE MULTIPLIERS

Waste Categories	Number of Buildings	Number of Residents	Number of Employees	Waste Multiplier	Tons/Year Total Solid Wastes
Industrial	545	N/A	16,000	6.74 tons/ employee year	107,000
Commercial	5,200	N/A	46,000	3.81 tons/ employee year	175,000
Commercial/ Industrial	530/100	N/A	4200/3000	6.74/3.81	28,308/11,430
Single Family Dwellings (Low Density)	75,000	195,000 @2.6 persons/ residence	N/A	1.43 tons/ unit/year	107,250
Single Family Dwellings (High Density)					
Multi-Family Dwellings	147 bldgs. 22,639 units	40,750 @1.8 persons/ residence	N/A	0.66 tons/ unit/year	15,000
Open Space Improved	N/A	N/A	N/A	N/A	*
Open Space Unimproved	N/A	N/A	N/A	N/A	*
Agricultural	N/A	N/A	N/A	N/A	*
Public Relations	N/A	N/A	N/A	N/A	*

NOTE: Average number of employees per industrial or commercial unit based on decennial census data.

TABLE 9. APPLICATIONS OF REMOTE SENSING TO SOLID-WASTE MANAGEMENT AND PLANNING*

Solid-Waste Applications	Remote-Sensing Record	Remote-Sensor Platform Used	Remote Sensor Applications (Preliminary)
Waste Quantities, Characteristics, and Distributions	Color-Infrared Photographs 1:120,000 Scale (Note: Color-IR is Preferred Over Natural Color Photographs at High Altitude Due to Better Building/Vegetation Contrasts and Color-IR's Haze Penetration Capability)	High Altitude Aircraft	- Solid-waste source areas-industry, commercial, residential, open space, recreational and agricultural can be delineated. - Spatial distribution of solid-waste source areas can be shown. - An inventory of buildings (type and number) can be made. - Area size and location of open space and recreation areas can be computed. - General nature of solid waste associated with waste sources can be determined. For example, paper, metals and organic materials associated with household wastes. - Gross regional population estimates can be made. (Requires collateral data giving, for example, average occupance per single- or multiple-family dwelling, or average number of employees per industry.) - Quantities of waste within waste source areas and for a region can be estimated (with waste multipliers).
	Panchromatic or Natural Color Stereo Photographs 1:24,000 Scale	Low Altitude Aircraft	- Within industrial areas an inventory of building type and type of industrial activity can be made. - Computations of floor space and estimated number of employees can be made. - Waste quantities can be computed using detailed industrial waste multipliers, i.e. average quantity of waste generated per industrial employee based on spot-sampling.

*Although this paper is oriented toward applications of Remote Sensing to determining waste distributions, characteristics and quantities, this table summarizes on-going Remote-Sensing/Solid-Waste research by the Authors. It is preliminary and subject to modification.

TABLE 9 CONTINUED

Solid-Waste Applications	Remote-Sensing Record	Remote-Sensor Platform Used	Remote Sensor Applications(Preliminary)
Waste Quantities Characteristics, and Distributions	Historical Panchromatic or Color IR Photography 1:24,000 to 1:120,000 Scale	Low to High Altitude Aircraft	- Changes over time within waste source areas can be studied and a region's future waste generating trends may be predicted. - Direction of urban expansion can be determined and potential waste disposal areas in danger of urban encroachment identified.
Waste Disposal Site Slection and Utilization (Includes: Sanitary Landfill; Incinerators; Recycling and Separation Facilities)+	Color infrared Photography 1:63,000 to 1:120,000 (Note: Color IR is Preferred Over Natural Color Photography at High Altitude Due to High Tonal Contrasts Between Vegetation/Bare Ground and Cultural Features)	High Altitude Aircraft	- Regional Geology (Especially important when siting sanitary landfills). - Regional Hydrology (particularly surface drainage). - Regional Land Use-the availability of open lands suitable for siting waste disposal sites and the relationship of these areas to surrounding cultural features, e.g., local communities or recreational areas can be determined. - Haul Distances-distances from major (urban) waste source areas to waste disposal areas may be computed. - Transportation Routes-major transportation routes from waste source areas to proposed waste disposal area can be identified. - Spatial Distribution of Waste Source Areas. For example, if residential wastes are concentrated in the northern section of an urban area, this may affect the siting of a separation facility geared solely to residential wastes. Economic factors such as transportation costs must be considered. - Waste Quantities-this will determine the number, size or type of waste disposal sites needed for a given region. - Waste Characteristics-may determine the type of waste disposal site(s) needed for the region.

+ Other parameters which are not amenable to study using remote sensing must be investigated when selecting waste disposal sites. Zoning regulations and social attitudes, for example, must be considered.

TABLE 9. CONTINUED

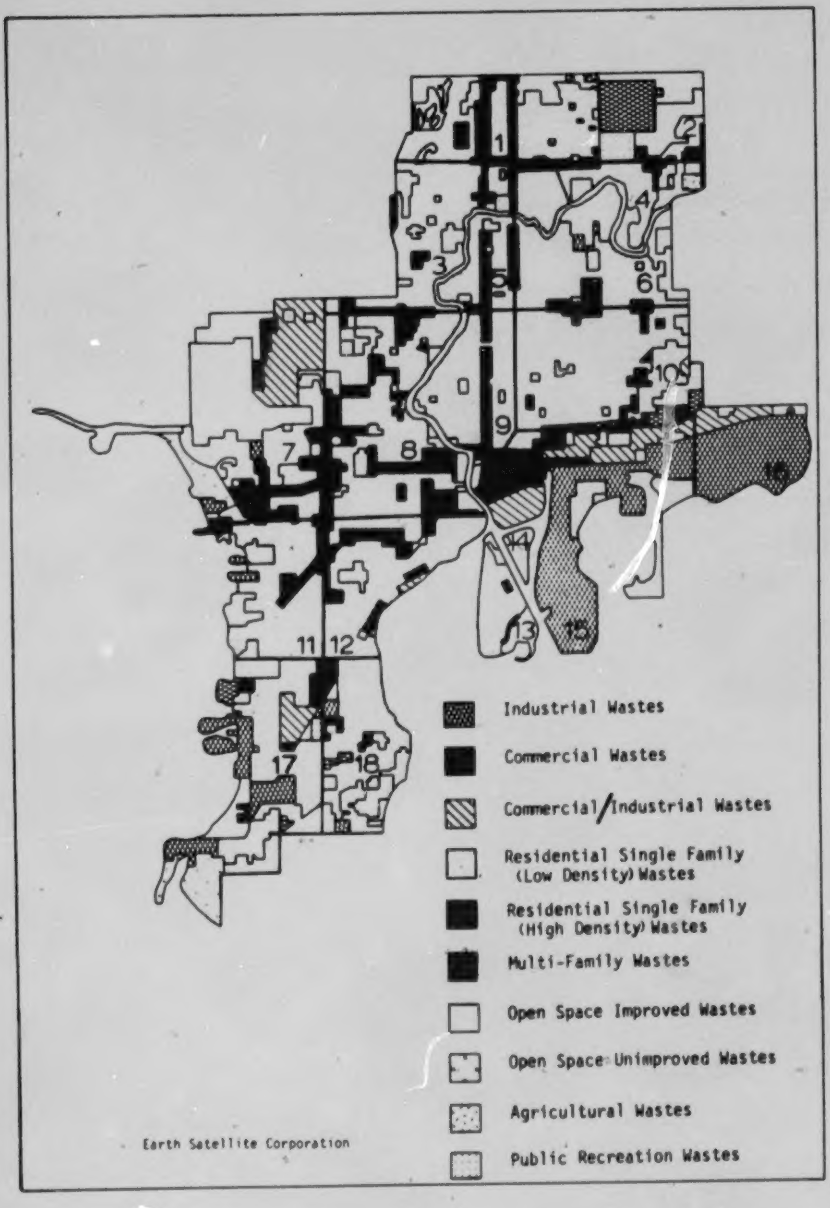
Solid-Waste Applications	Remote-Sensing Record	Remote-Sensor Platform Used	Remote Sensor Applications(Preliminary)
Waste Disposal Site Selection and Utilization (included: Sanitary Landfill; Incinerators, Recycling and Separation Facilities)+			- Location of existing excavation (quarries, strip mines etc.) which could be used as waste disposal sites.
Waste Disposal Site Selection Utilization	Natural Color Color Infrared 1:12,000 Scale (Stereoscopic Coverage)	Low Altitude Aircraft	- Local (proposed site) Geology and Geomorphology. - Local Hydrology-drainage, ponding, potential flood areas. - Potential effects of site location on local communities. - Analysis of vegetation at potential site (may be indicative of soil or drainage variations). - Access to proposed site-the availability and quality of access roads can be determined. - Capacity of existing excavations-life of the site can be estimated.
Waste Collection and Transportation	Color Infrared, Natural Color, Panchromatic 1:63,000 to 1:120,000	High Altitude Aircraft	- Major road networks can be mapped. (These may lead from major waste source areas to existing or proposed waste disposal areas, or from separation facilities to recycling centers.) - Spatial relationship between rail lines and recycled materials shipping points can be determined. - Waterways for movement of disposable wastes or recycled materials can be mapped.

+ Other parameters which are not amenable to study using remote sensing must be investigated when selecting waste disposal sites. Zoning regulations and social attitudes, for example, must be considered.

TABLE 9. CONTINUED

Solid-Waste Applications	Remote-Sensing Record	Remote-Sensor Platform Used	Remote Sensor Applications (Preliminary)
Waste Collection Transportation			- Street patterns within industrial, residential and commercial waste source areas can be identified and mapped. Once disposal sites are known order of collection within waste source areas can be determined along these identified collection routes. - Estimation of time needed to complete collection and transportation to disposal site (assuming availability of statistics on rates of vehicle movement).
	Panchromatic 1:2400 to 1:10,000 scale	Low Altitude Aircraft	- Traffic surveys to determine optimum time of day for collection and transportation of solid wastes.
Environmental Impace of On-Site Disposal (Site Suitability)	Natural Color Color Infrared Photography 1:12,000 Scale	Low Altitude Aircraft	- Changing water quality adjacent to and within waste disposal sites. - Vegetation destruction within and adjacent to site. - Sheet, rill and gully erosion. - Stream sedimentation from surface runoff. - Stockpiling of hazardous or polluting materials in environmentally "unsafe" areas. - Effects of site operation on wildlife habitats. - Formation of precarious embankments or scarps. - Aesthetic pollution (landscape scarring, abandoned equipment etc.) - Destruction of valuable wildlife resources during site expansion.
	Thermal Imagery ΔT 1°C	Low Altitude Aircraft (Helicopter)	- Underground fires associated with landfills can be detected. - Lechate-polluted outfalls in streams can be detected.

Figure 1. A color reproduction of a 1:120,000 scale color-infrared photograph. Two photographs were spliced together in order to center on the city of Tampa, Florida. Through interpretation of this photograph the city was divided into 10 waste source areas. Number of buildings within each waste source area and the areal size of each area was then computed. Using available wast multipliers, estimates of solid waste quantities for each waste source area were made. Waste multipliers assigned an average quantity of waste per unit of time to each waste source unit, e.g., tons of waste generated per single-family dwelling per year.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Industrial Wastes
Commercial Wastes
Commercial/Industrial Wastes
Residential Single Family (Low Density) Wastes
Residential Single Family (High Density) Wastes
Multi-Family Wastes
Open Space Improved Wastes
Open Space Unimproved Wastes
Agricultural Wastes
Public Recreation Wastes

Earth Satellite Corporation

Figure 2. Solid waste qnantities, characteristics and distributions in Tampa, Florida. (To be used in conjunction with Table 7).

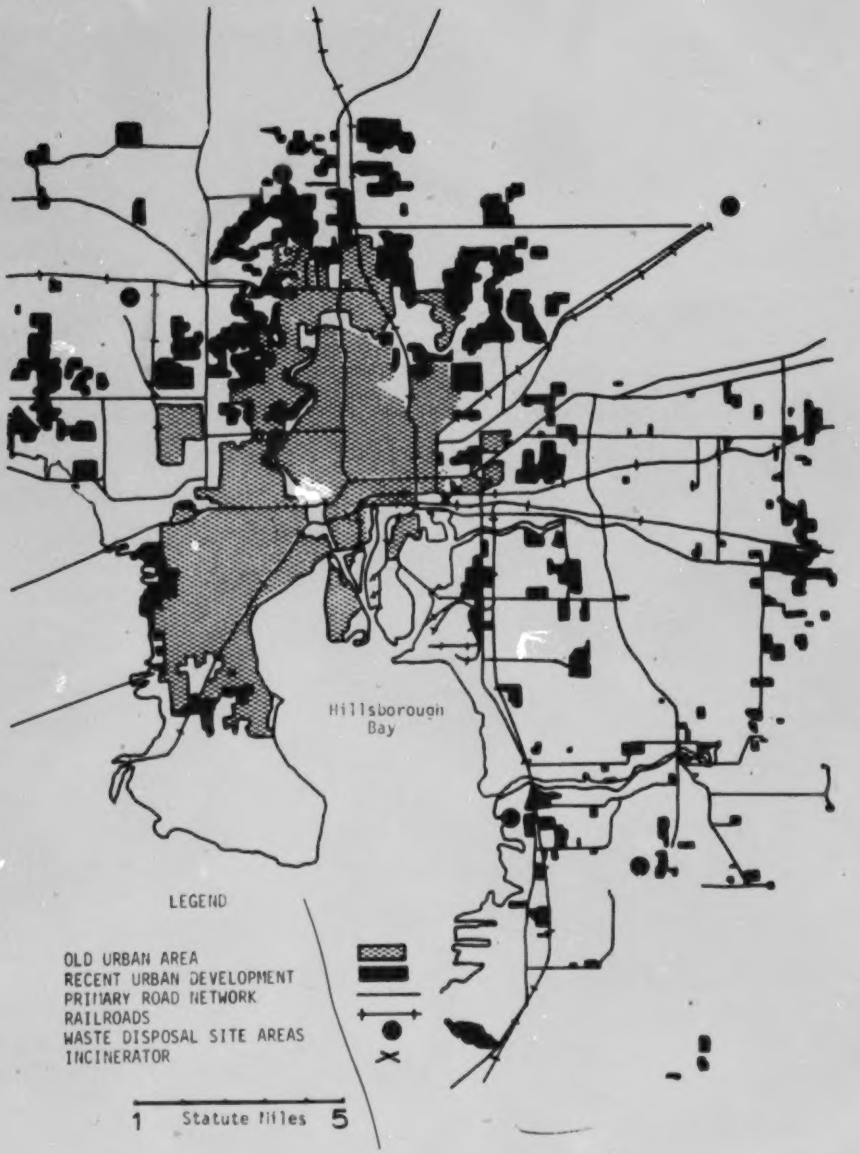
Hillsborough Bay
LEGEND
OLD URBAN AREA
RECENT URBAN DEVELOPMENT
PRIMARY ROAD NETWORK
RAILROADS
WASTE DISPOSAL SITE AREAS
INCINERATOR
1 Statute Miles 5

Fig. 3. Urban growth in Tampa, Florida, metropolitan area.

SOLID WASTE

Vocabulary - Define the following terms in detail.

Solid waste
Environmental degradtion
Color infrared
1:120,000
Urban

Questions - Answer the following inquires in detail.

1. What five parameters were used to obtain data?
2. What is the solid waste estimation technique?
3. Explain a field survey technique.
4. Using Table 3, make a graph by region for all 12 categories. What conclusions do you draw for each category for Region IV?
5. Table 4 has 7 categories with "insufficient data". Why?
6. What parameters must a waste prediction model include?
7. Explain waste multipliers.
8. What is the role of remote sensing in waste charting? Use Table 9.
9. What is the difference between imagery taken from low altitude and high altitude as related to Table 9?

Discussion Topics

1. Any population produces waste, so what in your opinion is a good method of disposal and why?
2. Discuss recycling of waste materials.

SECTION THREE

LABORATORY EXCURSIONS

FOREWORD

The laboratory activities contained in Section Three are designed to develop student skills in the areas of map reading, the spectrum, and other topics which relate to remote sensing. These excursions, however, are not intended to be the sole laboratory activities for the course. They serve as a "starter" to assist the student and teacher in understanding applications of remotely sensed technology.

These laboratory excursions are only bounded by the imagination of the students and the teachers. As students progress through these planned activities , many new ideas will come to mind. Students should be encouraged to design their own unit projects based on individual interests. Teachers should assign class projects to meet special interests and group needs. This section, then, is a foundation to build upon, to create, to design, and to meet the needs and desires of learners. To limit a mind's growth pattern here would inhibit intellectual growth.

This section also demonstrates that the use of scientific methods is extremely important when studying remote sensing. This new science is truly interdisciplinary in nature, combining many physical laws of science with the biological concepts of the specific problem. This approach is needed to facilatate the answering of the scientific inquiry at hand.

1. SCALE, DISTANCE, AND SYMBOLS

Activity Note

The scale of a map is the ratio between a distance on the map and the same distance measured on the Earth. For example, a scale of 1 inch to 100 miles means that 1 inch on the map represents 100 miles on the Earth's surface. Map scales may be verbal, like the example just given. They may be given as fractions like 1: 10,000. They may also be drawn on the map sheet as graphic scales.

Map symbols are used to show such features as houses, roads, railroads, ferries, bridges, lighthouses, and swamps. Those used on United States Geological Survey topographic sheets are illustrated and described on a map symbol sheet published by the survey.

Materials for Laboratory Unit Group

1 USGS Map of Cape Canaveral, 7.5 minute series, photorevised 1970
1 12" ruler in British or metric units
1 USGS Topographic Map Symbol Sheet or Geological Survey Circular 368,
"Features Shown on Topographic Map"
1 hand lens

Procedure

Have your students answer these questions:

1. The representative fraction form of the scale appears directly below the words Cocoa Beach. What is it? ______________________________
   This says that one unit of distance on the map represents 24,000 of the same units on the ground.

2. The graphic scale appears below the map. Measure it with a ruler. What is the scale? 1 inch ____________________ mile.

3. State the following scales in words and then draw a graphic scale for each:

FRACTION	SCALE IN WORDS	GRAPHIC SCALE
1: 62,500		
1: 125,000		
1: 250,000		
1: 63,360		
1: 31,860		

2. CONTOUR MAP READING

Activity Note

Using the information available on the map, have the students answer the following questions.

Materials for Laboratory Unit Group

Contour map appropriately marked

Procedure

Study this contour map and answer the following questions.

1 What is the elevation of point C?

2 What is the maximum elevation of point E?

3. What is the elevation of point F?

4. What is the elevation of point D?

5. What is the general direction in which the river is flowing?

6. What is the distance from point A to point B?

7. What is the gradient of the river from point B to point A?

8. What direction is point E from point C?

3. LATITUDE, LONGITUDE, AND LOCATION

Activity Note

The United States Geological Survey has prepared large-scale maps of much of the United States to systematize mapping. The country is divided by lines of latitude and longitude into quadrangles of definite areas with definite boundaries. The most common areas mapped are: (1) 1/4 degree latitude x 1/4 degree longitude (since 1/4 degree equals 15 minutes, these maps are said to be in the 15 minute series) and (2) 1/8 degree latitude x 1/8 degree longitude (since 1/8 degree equals 7.5 minutes, these maps are in the 7-1/2 minute series).

Each quadrangle sheet is given a name, usually of an important town or feature on that map.

Materials for Laboratory Unit Group

1 hand lens
1 USGS map of Florida from LANDSAT (44" x 58")
1 USGS map of Cape Canaveral, 7.5 minute series, photorevised 1970

Procedure

The Cape Canaveral Sheet covers an area 7.5 minutes (or 1/8 degree) in latitude and 7.5 minutes in longitude. The map follows the usual arrangements, having north at the top, south at the bottom, east to the right, and west at the left.

Have your students answer these questions

1. What is the latitude of the southern parallel of the map? Of the northern parallel?
2. How many minutes of latitude does the map include?
3. How do you know whether it is north latitude or south latitude?
4. What is the longitude of the eastern meridian of the map? Of the western meridian?
5. How many minutes of longitude does the map include?
6. How do you know whether it is east longitude or west longitude?
7. Describe the location of the Cape Canaveral quadrangle in the State of Florida, referring to the sketch map in the lower right margin.

4. SLOPE AND OCEAN BOTTOM

Activity Note

To determine the steepness of a hill, we must determine how much the land rises in a given distance. The rise may be read from the contours. The distance is determined by the scale. Remember, contours tell us only about elevation, or up and down distance. Horizontal distance along the ground must be measured on the scale of the map.

Materials for Laboratory Unit Group

1 USGS map of Cape Canaveral, 7.5 minute series, photorevised 1970
1 hand lens
1 12" ruler in British or metric units

Procedure

Have your students answer the following questions:

1. What is the scale of this map?
2. What is the contour interval?
3. How high above sea level is the contour interval at Cape Canaveral Lighthouse?
4. State the relationship between steepness of slope and spacing of contour lines.
5. Discuss the ocean depth and direction of flow starting at Canaveral Bight south to the town of Cape Canaveral. What is the effect of the jetty?

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5. LIGHT

Activity Note

This exercise will demonstrate reflection, absorption, and diffusion. These are the key principles in light transmission and are easily understood by the student.

Reflection is the bouncing of light off of an object. Absorption is the absorbing of light by an object. Diffusion is the scattering of light in all directions after striking an object.

Materials for Laboratory Unit Group

1 table lamp
1 8" x 11" sheet of black paper
1 500 ml beaker of murky water
1 small 3" x 5" mirror
1 8" x 11" sheet of white unlined paper (rough texture)

Procedure

For light reflection, have the student shine a light on the mirror and orient it so that the light is reflected on to another surface. Emphasize to the student that the light is being reflected.

For light absorption, have the student reflect light from the mirror onto a sheet of white paper and a sheet of black paper in turn. While the light can be seen on the white paper, very little of it shows on the black paper. This is because the black paper has absorbed the light.

For light diffusion, have the student shine the light on white paper. The light is diffused, or scattered in all directions, due to the texture of the paper.

6. MOUNTAIN MAPPING

Activity Note

Mapmakers have devised many different ways to show the topography or land forms of a region on maps. The most common method uses lines called contours. The maps on which they are used are called contour maps or topographic maps. The contour map is a planar projection of these contour lines onto an imaginary flat surface.

In this exercise we shall make a contour map of a mountain model to help us understand what contour lines are and how they show landforms.

Materials for Laboratory Unit Group

1 piece of modeling clay
1 large battery jar
1 sheet of onion skin paper
1 glass plate to cover battery jar
1 glass marking crayon
1 12" ruler in British or metric units
1 jar of food coloring

Procedure

Use the modeling clay to make a cone shaped mountain 3" high with a base that will fit in the battery jar. Make the cone asymmetrical--steeper on one side than on the other. Then, mold the onion skin paper over the mountain.

Next utilizing the glass marking crayon, mark the outside of the battery jar from the bottom up with short horizontal lines, spaced at intervals of 1/2 inch, up to the height of your mountain.

Place the mountain in the battery jar. Carefully pour in water colored with food coloring until the first 1/2 inch mark is reached. Then use the marking crayon to draw a line around the mountain showing the exact level of the water. Repeat this process at each 1/2 inch level until the top of mountain is reached. Each line you have drawn is a contour line.

7. LOCATING POINTS IN ROCKLEDGE, FLORIDA

Activity Note

The purpose of this laboratory exercise is to assist the student in locating points on a map by section, township, and range.

Materials for Laboratory Unit Group

1 12-inch ruler in British or metric units
1 180° protractor
1 township map of Rockledge

Procedure

Complete the numbering of the sections on the map.

1. What is the feature in Sec. 23, T26S, R36E?

2. The rectangle inside the City of Rockledge, at the time the map was made, was not included as part of the city. What is the description of the rectangle?

3. Construct a graphic scale to 1/8-mile smallest division for the map. How long, to the nearest 1/8, is the power line running from the southwest corner of Rockledge to the building in Sec. 25, T25S, R35E?

4. To the nearest degree, what is the bearing of the power line?

5. To the nearest 1/8-mile, what is the map-measured length of I-95 on the map?

8. IDENTIFYING TITUSVILLE, FLORIDA LANDMARKS

Activity Note

The objective of this laboratory excursion is to assist the student in learning to read a topographic map of Titusville.

A series of questions will be asked of the student laboratory group that will allow the pupil units to display their skills in identification of objectives.

Materials for Laboratory Unit Group

1 USGS Map of Titusville, 7.5 minute series, photorevised 1970
1 sheet of 8 1/2" x 11" clean lined white paper

Inquiries

1. Briefly state what the color purple stands for on this map. ________________
   ____
2. What is the stated contour interval? ______________________________
3. What is the stated scale? ______________________________
4. Indicate the following features on your map:
   - A. Cemeteries
   - B. Titusville High
   - C. Ti-Co Airport
   - D. Drive-in Theater
   - E. Blue Hole
   - F. Airway Beacon
   - G. Water Tower
   - H. Brick Creek
   - I. Trailer Park
   - J. Radio Tower
   - K. Ruins
   - L. Yacht Basin
5. What is the depth of the **Intercoastal Waterway**?
6. Discuss the north-south connection between South Lake and Fox Lake.
7. List by direction the eight topographic maps adjacent to the Titusville map.
8. Give the symbols for road classification and route designations.
9. Why are there no appreciable tidal influences in this area?
10. What is the spoil area immediately next to the **Intercoastal Waterway**?

9. COCOA - MERRITT ISLAND, FLORIDA
TOPOGRAPHIC STUDY

Activity Note

The purpose of this laboratory exercise is to study the 1970 **photorevised area in purple.** This should give the student enough data to consider environmental stresses including transportation, land usage, recreation facilities, and urban expansion.

Materials for Laboratory Unit Group

1 USGS map of Cocoa, 7.5 minute series, photorevised 1970
1 **sheet** of 8 1/2" x 11" clean lined white paper

Inquiries

1. Estimate the percentage of land development that has occurred since 1949 in the color purple. ________________
   What is the reason for this expansion? ____________________________

2. Why is the Intercoastal Waterway narrow in Cocoa and wider around Bonaventure?

3. In the Thousand Islands, the Cocoa Beach Recreation Complex has been developed. What was the environmental impact on the surrounding islands?

4. What is your hypothesis for the formation of Honeymoon Lake?

5. What environmental problems were caused by the land based 520 Causeway?

6. Regarding the 520 Causeway, what would have been an alternative to construction of this transportation system?

7. In your opinion, what will be the needs of this area 20 years from now, assuming we have continued growth?

8. In the new urban areas, explain the placement of canals and the environmental factors which are associated with them.

10. FINDING NORTH

Activity Note

The magnetic compass points toward the magnetic north pole, a point located in northwestern Canada more than a thousand miles from the geographic pole. In most parts of the United States, the reading from the compass needle must be corrected by an angle called the magnetic declination or magnetic variation to find true geographic north.

The use of the Sun for finding north depends on the fact that when the Sun crosses the local meridian at noon, it is also at its highest point in the sky. At this time, the shadow of a vertical post is shortest and points toward the true north. Before or after noon, the Sun's position can also be used to find north, if proper corrections are made.

At night true geographic north can be found, within about half a degree, from the position of Polaris, the north star, in the handle of the Little Dipper.

Materials for Laboratory Unit Group

1 magnetic compass
1 12" ruler in British or metric units
1 wood pencil

Procedure

Place the magnetic compass on a horizontal surface and allow the needle to come to rest. Make certain that no iron or steel object is within two feet of the compass to deflect it. Record the position of the needle by marking the location of its ends on a sheet of paper that is lined up with the edge of your desk. Connect the two points with a ruler. This line, like the compass needle, points to the magnetic north pole.

To find geographic (true) north, you must correct the magnetic north by an angle equal to the magnetic variation of your locality. This information may be obtained from a USGS topographic map.

Use a protractor to correct the magnetic north line so that it points toward true north for your local variation. The direction of variation may be determined from the USGS topographic map.

Label the magnetic north and geographic north lines and the angle between them (the magnetic variation).

Check your results against the USGS topographic map.

11. IDENTIFYING THE THEMES OF CAPE CANAVERAL, FLORIDA

Activity Note

The object of this laboratory exercise is to identify different themes in an image. A theme uses color to indicate features of the same type. For example, urban areas might be shown in red, while fields and forests might be green.

In the picture of Cape Canaveral, have the student color each theme a different color. This will stimulate much discussion as to what is the predominate feature or theme.

Materials for Laboratory Unit Group

1 U-2 photograph of Cape Canaveral
1 clean, unlined sheet of white paper
1 set of colored pencils

Procedure

Have the student select four themes. These themes are man's cultural influence on the land, agriculture, water, and natural vegetation. Remember, each is a separate color. Question the student about man's impact on the environment.

12. OUR RAINBOW

Activity Note

It is important for the teacher to demonstrate a good color spectrum by use of the prism. This can be accomplished by holding the prism in front of a strong light source, such as a slide projector lens. This will assist the student in achieving a better spectrum when he performs this activity using a lamp or the Sun.

Materials for Laboratory Unit Group

1 small triangle prism
1 clean unlined sheet or white paper
1 table lamp for inside or sunny day for outside
1 viewgraph of spectrum (For teached demonstration)
1 overhead projector (For teacher demonstration)

Procedure

The student should find the angle for the prism which will give the best color spectrum. Have the student reflect this image on to a clean unlined sheet of white paper and record the colors. Each color corresponds to light of a particular wavelength which, when combined with the other colors, gives the white light of the source.

13. MAKING A SPECTROSCOPE

Activity Note

The spectroscope is an instrument that splits light into its separate wavelengths and colors. It consists of two parts: (l) a diffraction grating and (2) a viewing tube.

Materials for Laboratory Unit Group

1 cardboard tube 12" long
1 3" x 4" piece of cardboard
1 tube of glue
1 scissors
1 diffraction grating

Procedure

Cut a circular disk to fit the end of the tube from the piece of cardboard. Cut a slit 3/4" long and 1/32" wide in this disk. It is important that there be no ragged edges. Fasten the disk in the end of the tube with glue.

Now point the tube at an electric light with the slit vertical. Hold the diffraction grating over the open end of the tube, look through it, and turn it until it forms a horizontal spectrum. In this position, glue the grating mount to the tube.

14. USING YOUR SPECTROSCOPE

Activity Note

Using the spectroscopes made by the students, examine various sources of light.

Materials for Laboratory Unit Group

1 homemade spectroscope
1 source for incandescent light
1 source for fluorescent light
1 source for natural light
1 source for street light
1 source for advertising light

Procedure

Have the students examine different sources of light found in the classroom and/or the community. These sources may include an incandescent lamp, fluorescent lamp, natural light, street lamps, and advertising signs. Have the students record their findings.

15. THE COLOR OF MINERALS

Activity Note

The purpose of this exercise is to show how a basically colorless mineral may exhibit many shades of color. Certain minerals, such as quartz and calcite, are colorless when absolutely pure but may be pink, yellow, brown, smoke gray, green, and black when they contain even a small amount of dissolved "impurity."

This impurity is usually a metallic compound.

Materials for Laboratory Unit Group

1 nichrome wire with handle/chemical
1 sample of borax
1 sample of cobalt nitrate
1 sample of manganese dioxide
1 sample of copper sulfate
1 sample of ferric chloride
1 sample of chromium nitrate
1 sample of nickel chloride
1 Bunsen burner

Procedure

Place a nichrome wire with an 1/8" loop in the end of it into the flame of a Bunsen burner until it is red hot. Then dip this wire into one of the chemicals. (Never dip the same wire into more than one chemical.) Place the wire loop in the flame again and examine the resulting color with the stereoscope.

APPENDIX A

GLOSSARY OF TERMS

abrasions (abrasion marks): Streaks or scratches occurring on the emulsion surface of film base. Caused by grit or other foreign objects in the camera or processing equipment.

absolute altitude: Altitude above the actual surface of a planet or natural satellite, either land or water.

absorbed light: Light rays that are neither reflected nor transmitted when directed toward opaque or transparent materials.

Absorptance: The ratio of the radiant flux absorbed by a body to that incident upon it. Also called absorption factor. Compare absorptivity. Total absorptance refers to absorptance measured over all wavelengths; spectral absorptance is measured at a specified wavelength.

absorption: (1) The process by which radiant energy is absorbed and converted into other forms of energy. See attenuation. Absorption takes place only after the radiant flux enters a medium and thus acts only on the entering flux and not on the incident flux, some of which may be reflected at the surface of the medium. A substance which absorbs energy may also be a medium of refraction, diffraction, or scattering; these processes, however, involve no energy retention or transformation, and are to be clearly differentiated from absorption. (2) In general, the taking up or assimilation of one substance by another. See adsorption. (3) In vacuum technology, gas entering into the interior of a solid.

absorption band: A range of wavelengths (or frequencies) in the electromagnetic spectrum within which radiant energy is absorbed by a substance.

absorption factor: absorptance.

absorption line: A minute range of wavelengths (or frequencies) in the electromagnetic spectrum within which radiant energy is absorbed by the medium through which it is passing. Each line is associated with a particular mode of electronic excitation induced in the absorbing atoms by the incident radiation.

absorption spectrum: The array of absorption lines and absorption bands which results from the passage of radiant energy from a continuous source through a selectively absorbing medium cooler than the source. See electromagnetic spectrum. The absorption spectrum is a characteristic of the absorbing medium, just as an emission spectrum is a characteristic of a radiator. An absorption spectrum formed by a monatomic gas exhibits discrete dark lines, whereas that formed by a polyatomic gas exhibits ordered arrays (bands) of dark lines, which appear to overlap. This type of absorption is often referred to as line absorption. The spectrum formed by a selectively absorbing liquid or solid is typically continuous in nature (continuous absorption).

absorptivity: The capacity of a material to absorb incident radiant energy. A special case of absorptance, a fundamental property of material that has a specular (optically smooth) surface and is sufficiently thick to be opaque. It further may be qualified as spectral absorptivity. The suffix (-ity) implies a property intrinsic with a given material, a limiting value.

absorptivity-emissivity ratio: The ratio of absorptivity for solar radiation of a material to its infrared emissivity. Also called A/E ratio.

accommodation: (1) The faculty of the human eye to adjust itself to give sharp images for different object distances. (2) The ability of the eyes to bring two images into superimposition for stereoscopic viewing.

achromatic: Devoid of hue, or transmitting light without showing its constituent colors.

acronym: A "word" or term made up of the first or other letters of a phrase, as for example radar (radio detection and ranging).

actinometer: An instrument for measuring the actinic value of light according to a given **scale.**

active: Denotes a source of radiation external to the surface or object. Compare with passive.

active microwave: Ordinarily referred to as a radar.

active systems: (1) A system having its own source of EMR as for example a radar or an ultraviolet blacklight. (2) A system that measures EMR that is reflected from a surface or object, and not produced (emitted) by the surface or object. Compare passive systems.

acuity, visual: A measure of the human eye's ability to separate details in viewing an object. The reciprocal of the minimum angular separations, in minutes of arc, of two lines of detail which can be seen separately.

acutance: An objective measure of the ability of a photographic system to show a sharp edge between contiguous areas of low [illegible] high illuminance. This film property now can be measured, using microdensitometric techniques, instead of being qualitatively estimated by subjective visual perception.

adaption (ophthalmology): The faculty of the human eye to adjust its sensitivity to varying intensities of illumination.

additive color process: a method for creating essentially all colors through the addition of light of the 3 additive color primaries (blue, green, and red) in various proportions through the use of 3 **separate** projectors. In this type of process each primary filter absorbs the other 2 primary colors and transmits only about one-third of the luminous energy of the source. It also precludes the possibility of mixing colors with a single light source because the addition of a second primary color results in total absorption of the only light transmitted by the first color.

adsorption: The adhesion of a thin film of liquid or gas to the surface of a solid substance. The solid does not combine chemically with the adsorbed substance.

aerial film: A specially designed roll film supplied in many lengths and widths to fit aerial cameras. Emulsion types include panchromatic, infrared, color, and color infrared. Aerial panchromatic film is slightly higher than normal in red sensitivity. This provides high film speed for use through hazecutting filters. The film base often is specially prepared to have very low shrinkage.

aerial photograph, oblique: A photograph taken with the camera axis directed between the horizontal and the vertical. (1) high oblique: An oblique photograph in which the apparent horizon is shown. (2) low oblique: An oblique photograph in which the apparent horizon is not shown.

aerial photograph, vertical: An aerial photograph made with the optical axis of the camera approximately perpendicular to the Earth's surface and with the film as nearly horizontal as is practicable.

aerial photographs, composite: Aerial photographs made with a camera having one principal lens and two or more surrounding and oblique lenses **symmetrically** placed. The several resulting photographs may be rectified in printing to permit assembly as verticals with the same scale.

aerial photographs, overlapping: Two or more aerial photographs to which a portion of the total area projected thereon is common. Such photographs are used for stereoscopic studies and for making mosaics. Overlap may be end or forward (along the flight path) or side (taken during two or more parallel flights); both end and side overlap are customary when more than one line or strip is flown.

aerial reconnaissance: The securing of information by aerial photography or by visual observation from the air.

albedo: (1) The ratio of the amount of EMR reflected by a body to the amount incident upon it, often expressed as a percentage, as, the albedo of the Earth is 34 percent. (2) The reflectivity of a body as compared to that of a perfectly diffusing surface at the same distance from the Sun, and normal to the incident radiation (see band albedo, reflectance). Albedo is sometimes used to mean the flux of the reflected radiation as, the Earth's albedo is 0.64 calorie per square centimeter. This usage should be discouraged. Albedo may refer to the entire solar spectrum or merely to visible portion.

analog: (1. electra.) A physical variable which remains similar to another variable insofar as the proportional relationships are the same over some specified range; for example, a temperature may be represented by a voltage which is its analog. (2. meteorol.) A past large-scale synoptic weather pattern which resembles a given (usually current) situation in its essential characteristics.

angle of reflection: The angle which EMR reflected from a surface makes with the perpendicular (normal) to the surface.

angle of refraction: The angle made by the refracted ray with the incident ray when a ray of light passes through a transparent substance. The refracted ray is bent at an angle from the line of the incident ray.

angle of sun: The angle of the sun above the horizon. Not only the quantity (lumes) of light being reflected to the aerial camera but also the spectral quality, are influenced by sun-angle. Also called sun elevation, sun elevation angle.

angle of view: The angle subtended by lines which pass through the center of the lens to diametrically opposite corners of the plate or film used. The angle of view of the camera varies with the photographed image and the bellows extension. The area covered by an aerial camera at a given altitude may be calculated from the angle of view.

angstrom (A): Unit of measurement, 10^{-10} m.

aperture: The opening in a lens diaphragm through which light passes.

aperture, effective: The unobstructed useful area of the orifice through which the ray of light passes to the film to produce the image. This is smaller than the actual area of the hole due to the effects of diffraction or bending of the rays near the edges.

aperture, relative: The ratio of the equivalent focal length to the diameter of the entrance "pupil" of a photographic lens. Expressed "f:4.5," etc. Also called "f-number," "stop," "aperture stop," "speed."

aperture stop (optics): The physical element (such as a stop, diaphragm, or lens periphery) of an optical system which limits the size of the pencil of rays traversing the system. The adjustment of the size of the aperture stop of a given system regulates the brightness of the image without necessarily affecting the size of the area covered. field stop: The physical element (such as a stop, diaphragm, or lens periphery) of an optical system which limits the field of view covered by the system. entrance pupil: The image of the aperture stop formed by all the lens elements on the object side of the aperture stop. exit pupil: The image of the aperture stop formed by all the lens elements on the image side of the aperture stop. entrance window: The image of the field stop formed by all the lens elements on the object side of the field stop. exit window: The image of the field stop formed by all the lens elements on the image side of the field stop. field of view: (1) optics: The angular coverage of a lens system, equal to the angle subtended by the diameter of the entrance window at the center of the entrance pupil. (2) photogrammetry: The angular coverage of a photograph, equal to twice the angle whose tangent is one-half the length of the diagonal (or diameter) of the photograph giving satisfactory definition, divided by the calibrated focal length of the camera.

aperture, working: The largest diaphragm opening at which a lens gives satisfactory definition over the area of a film or plate which is covered by an image.

attenuation: In physics, any process in which the flux density (or power, amplitude, intensity, illuminance,) of a "parallel beam" of energy decreases with increasing distance from the energy source.

attitude: (1, photogrammetry). The angular orientation of a camera, or of the photograph taken with that camera, with respect to some external reference system. Usually expressed as tilt, swing, and azimuth; or roll, pitch, and yaw. (2, platforms). The angular orientation of an aerial or space vehicle with respect to a reference system.

back (backward) scatter: The scattering of radiant energy into the hemisphere of space bounded by a plane normal to the direction of the incident radiation and lying on the same side as the incident ray; the opposite of forward scatter. Also called backscattering. Atmospheric backscatter depletes 6 to 9 percent of the incident solar beam before it reaches the earth's surface. In radar usage, backscatter generally refers to that radiation reflected back toward the source.

background: Any effect in a sensor or other apparatus or system above which the phenomenon of interest must manifest itself before it can be observed. See background noise.

background luminance: In visual-range theory, the luminance (brightness) of the background against which a target is viewed.

background noise: (1) In recording and reproducing, the total system noise independent of whether or not a signal is present. The signal is not to be included as part of the noise. (2) In receivers, the noise in the absence of signal modulation on the carrier. Ambient noise detected, measured, or recorded with the signal becomes part of the background noise. Included in this definition is the interference resulting from primary power supplies, that separately is commonly described as hum.

band: (1) A selection of wavelengths. (2) Frequency band. (3) Absorption band. (4) A group of tracks on a magnetic drum. (5) A range of radar frequencies, such as X-band, Q-band.

band-elimination filter: A wave filter that attenuates one frequency band, neither the critical nor the cutoff frequencies being zero or infinite.

band-pass filter: (2) A wave filter that has a single transmission band extending from a lower cutoff frequency greater than zero to a finite upper cutoff frequency.

bandwidth: (1) In an antenna, the range of frequencies within which its performance, in respect to some characteristic, conforms to a specified standard. (2) In a wave, the least frequency interval outside of which the power spectrum of a time-varying quantity is everywhere less than some specified fraction of its value at a reference frequency. (3) The number of cycles per second between the limits of a frequency band. Sense 2 permits the spectrum to be less than the specified fraction within the interval. Unless otherwise stated, the reference frequency is that at which the spectrum has its maximum value.

bar: Unit of pressure equal to 10^6 dynes cm^{-2}.

bar scale: A graduated line on a map, plan, photograph, or mosaic, by means of which actual ground distances may be determined. Also called graphic scale.

base, film: A thin, flexible, transparent sheet of cellulose nitrate, acetate, or similar material which is coated with a light-sensitive emulsion and used for taking photographs. Cellulose acetate is practically nonflammable, whereas cellulose nitrate is highly flammable.

biosphere: A term sometimes applied to that portion of the Earth occupied by the various forms of life.

bird: A rocket, satellite, or spacecraft.

blackbody, black body, (symbol bb used as subscript): An ideal emitter which radiates energy at the maximum possible rate per unit area at each wave-length for any given temperature. A blackbody also absorbs all the radiant energy incident upon it. No actual substance behaves as a true blackbody although platinum black and other soots rather closely approximate this ideal. In accordance with Kirchhoff's law, a blackbody not only absorbs all wavelengths, but emits at all wavelengths and does so with maximum possible intensity for any given temperature.

black-body emission: Black-body radiation.

black-body radiation: The electromagnetic radiation emitted by an ideal black body; it is the theoretical maximum amount of radiant energy of all wavelengths which can be emitted by a body at a given temperature. The spectral distribution of black-body radiation is described by Planck's law and related radiation laws. If a very tiny opening is made into an otherwise completely enclosed space (hohlraum), the radiation passing out through this hole when the walls of the enclosure have come to thermal equilibrium at some temperature will closely approximate ideal black-body radiation for that temperature.

blow-up: Photographic slang meaning to enlarge or an enlargement.

brightness: (1) The attribute of visual perception in accordance with which an area appears to emit more or less light. (2) Luminance. (3) The luminous flux emitted or reflected per unit projected area per unit solid angle. The unit of brightness, the lambert is defined as brightness of a surface which emits or reflects one/π lumen per square centimeter per steradian. The stilb is the unit of brightness of a surface which has, in the direction considered, a luminous intensity of one candle per square centimeter. In sense (2) luminance is preferred.

brightness range (photography): The ratio of the apparent brightness of highlights to the deepest shadow in the actual scene as measured from the camera station.

brightness temperature: (1) The temperature of a blackbody radiating the same amount of energy per unit area at the wavelengths under consideration as the observed body. Also called effective temperature. (2) The apparent temperature of a non-blackbody determined by measurement with an optical pyrometer or radiometer.

brilliance: The degree of intensity of a color.

calibration: The act or process of comparing certain specific measurements in an instrument with a standard.

calibration templet (photogrammetry): A templet of glass, plastic, or metal made in accordance with the calibration constants to show the relationship of the principal point of a camera to the fiducial marks; used for the rapid and accurate marking of principal points on a series of photographs. Also, for a multiple-lens camera, a templet prepared from the calibration data and used in assembling the individual photographs into one composite photograph.

Callier quotient: The ratio between diffuse and specular density as measured on a given photographic emulsion; also called "Q-Factor."

camera: A lightproof chamber or box in which the image of an exterior object is projected upon a sensitized plate or film, through an opening usually equipped with a lens or lenses, shutter, and variable aperture.

camera, aerial: A camera specially designed for aerial use.

camera, multiband: A camera that exposes different areas of one film, or more than one film, through one lens and a beam splitter, or two or more lenses equipped with different filters, to provide two or more photographs in different spectral bands.

camera, multiple lens: A camera with two or more lenses, the axes of the lenses being systematically arranged at a fixed angle to cover a wide field by simultaneous exposures in all chambers. In most such cameras the oblique lenses are arranged symmetrically around a central lens.

camera, panoramic: A camera with a very wide angle of view, up to horizon to horizon, usually by means of a moving (sweeping) lens.

camera port: The opening in the body or hull of a remote sensor platform, through which the camera is operated.

camera station: The point in space, in the air or on the ground, occupied by the camera lens at the moment of exposure. Also called the exposure station. In aerial photography the camera station is called the "air station."

camera, surveying: A camera specially designed for obtaining photographs to be used in surveying. The camera is equipped with a mechanism to maintain and to indicate the interior orientation of the photographs with sufficient accuracy for surveying purposes.

camera tube: An electron-beam tube used in a television camera, in which an electron current or charge-density image is formed from an optical image and scanned in a predetermined sequence to provide an electrical signal output.

candela (formerly candle): The international unit of luminous intensity; the luminance of a blackbody radiator at the temperature of solidification of molten platinum is 60 candelas per sq. cm. The candela corresponds to one lumen per steradian.

candlepower: Luminous intensity expressed in terms of the candela.

Cartesian coordinates: A coordinate system in which the locations of points in space are expressed by reference to three planes, called coordinate planes, no two of which are parellel.

cartography: Map and chart construction.

ceiling (aerospace): (1) The height above the earth's surface of the lowest layer of clouds or obstruction phenomena that is reported as broken, overcast, or obscuration and not classified as thin, or partial. (2) The maximum altitude at which an aircraft can fly.

celestial sphere: An imaginary sphere of infinite radius concentric with the earth, on which all celestial bodies except the earth are assumed to be projected.

cell: An area on the ground from which EMR is emitted or reflected.

cell, photoelectric: A device by which light is transformed into electrical energy. It can be used to activate a camera shutter or other device, or to measure the intensity of light.

Celsius (°C): A temperature scale in which the freezing point of water is labelled 0° and the boiling point 100°; formerly called centigrade temperature scale. (The Ninth General Conference on Weights and Measures (1948) replaced the designation degree centigrade by degree Celsius.)

centigrade (°C): Now known as Celsius.

centimeter (cm): A measure of length, 1/100 of a meter; approximately 0.3937 U.S. inch, exactly 1/2.54 inch.

chart, aeronautical: A map especially designed for the aviator, on which, in addition to essential topography, are shown obstructions, aids to navigation, and other information to assist the aviator in navigating.

chart, hydrographic: A hydrographic or marine map; A map of a portion of the earth's surface which includes navigable waters and the adjacent or included land, if any, and on which are indicated depths of water, marine obstructions, aids to navigation, and any other information to aid the mariner in navigating. Also called nautical chart.

chart, nautical: See chart, hydrographic.

chemosphere: The vaguely defined region of the upper atmosphere in which photochemical reactions take place. It is generally considered to include the stratosphere (or the top thereof) and the mesosphere, and sometimes the lower part of the thermosphere. This entire region is the seat of a number of important photochemical reactions involving atomic oxygen O, molecular oxygen O_2, ozone O_3, hydroxyl OH, nitrogen N_3, sodium Na, and other constituents to a lesser degree.

chromopaque: A color print.

color: That property of an object which is dependent on the wavelength of the light it reflects or, in the case of a lumincescent body, the wavelength of light that it emits. If, in either case, this light is of a single wavelength the color seen is a pure spectral color; but if light of two or more wavelengths is emitted, the color will be mixed. White light is a balanced mixture of all the visible spectral colors.

color balance: The proper intensities of colors in a color print, positive transparency, or negative, that give a correct reproduction of the gray scale (as faithful as can be achieved by photographic representation of the true colors of a scene.)

color composite (multiband photography): A color picture produced by assigning a color to a particular spectral band. In ERTS, ordinarily blue is assigned to band 1 or 4 (~500 to 600 mm), green to band 2 or 5 (~600 to 700 mm), and red to band 3 (~700 to 1 um) or 7 (~800 to 1.1 um), to form a picture closely approximating a color-infrared photograph.

color sensitivity: The sensitivity of a photographic emulsion to light of various wavelengths.

color temperature: An estimate of the temperature of an incandescent body, determined by observing the wavelength at which it is emitting with peak intensity (its color) and applying the Wien law. If such a body were an ideal blackbody, the temperature so estimated would be its true temperature and would also agree with its effective temperature; but for actual bodies, the color temperature is generally only an approximate value. Thus, the sun's color temperature is about 6100 °K, a few hundred degrees hotter than most approximations of its effective temperature. (2) The temperature to which a blackbody radiator must be raised in order that the light it emits may match a given light source in color. (Usually expressed in degrees Kelvin °K). Compare with brightness temperature.

composite photograph (aerial photography): A photograph made by assembling the separate photographs, made by the several lenses of a multiple-lens camera in simultaneous exposure, into the equivalent of a photograph taken with a single wide-angle lens.

continuous spectrum: (1) A spectrum in which wavelengths, wave numbers, and frequencies are represented by the continuum of real numbers or a portion thereof, rather than by a discrete sequence of numbers. See absorption spectrum. (2) For EMR, a spectrum that exhibits no detailed structure and represents a gradual variation of intensity with wavelength from one end to the other, as the spectrum from an incandescent solid. Also called continuum, continuum radiation. (3) For particles, a spectrum that exhibits a continuous variation of the momentum or energy.

contrast (photography): The difference between highlights and shadows. The ratio of reflecting power between the highlights and shadows of a print determines the contrast. Contrast in a negative is determined by the ratio of densities of the parts compared. The amount of contrast in a finished photograph may be attributed to several factors: the exposure given the negative, the filter used, the type of film, the duration of development, the duration of exposure and development in printing, the paper used in printing, and the developer used both for the negative and the print.

coordinates: Linear or angular quantities which designate the position of a point in a given reference or grid system.

coordinates, geographic: A system of spherical coordinates for describing the positions of points on the earth. The declinations and polar bearings in this system are the latitudes and longitudes, respectively.

coverage: The ground area represented on aerial photographs, photomosaics or maps.

data processing: Application of procedures -- mechanical, electrical, computational, or other--whereby data are changed from one form into another.

data reduction: Transformation of observed values into useful, ordered, or simplified information.

deci (abbr. d): A prefix meaning multiplied by 10^{-1}; one-tenth.

definition (photography): The degree of sharpness, that is, distinctness of small detail in the picture, image, negative, or print.

densitometer: An instrument for the measurement of optical density (density of the silver deposit) (photographic transmission, photographic reflection, visual transmission, etc.) of a material, generally of a photographic image. There are many varieties, but all are alike in providing means for reducing the intensity of a standard light constantly until it matches an identical beam of light which has passed through the material being measured.

density (abbr. D): A measure of the degree of blackening of an exposed film, plate, or paper after development, or of the direct image (in the case of a printout material. It is defined strictly as the logarithm of the optical opacity, where the transmitted (or reflected) light, or transmissivity, T, as $D = \log (1/T)$. It varies with the use of scattered or specular light.

detector (radiation): A device providing an electrical output that is a useful measure of incident radiation. Broadly divisible into two groups-thermal, sensitive to temperature changes-and photodetectors, sensitive to changes in photon flux incident on the detector. May also include antennas and film. Typical thermal detectors are thermocouples, thermopiles, and thermistors-the latter is termed a bolometer. Typical photodetectors are either photovoltaic (voltage changes), e.g., InSb, or photoconductive (conductivity change), e.g., PbS, doped-germanium, etc. A new group of photoconductive trimetal detectors is becoming important, e.g., HgCdTe alloy detector.

develop(ment)(photography): To subject to the action of chemical agents for the purpose of bringing to view the invisible or latent image produced by the action of light on a sensitized surface; also, to produce or render visible in this way.

diffraction: The propagation of EMR around the edges of opaque objects into the shadow region. A point of light seen or projected through a circular aperture will always be imaged as a bright center surrounded by light rings of gradually diminishing intensity in the shadow region. Such a pattern is called a diffraction disk, Airy disk, or centric.

diffuse light: Light that does not reach the subject from a single direction. Sunlight which has been scattered by the atmosphere or clouds.

diffuse radiation: A more general term than diffuse light; refers to all EMR scattered by whatever means.

diffuse reflection: The type of reflection obtained from a relatively rough (in terms of the wavelength of the EMR) surface, in which the reflected rays are scattered in all directions.

diffuse reflector: Any surface which reflects incident rays in a multiplicity of directions, either because of irregularities in the surface or because the material is optically inhomogeneous, as a paint; the opposite of a specular reflector. Ordinary writing papers are good examples of diffuse reflectors, whereas mirrors or highly polished plates are examples of specular reflectors in the visible portion of the EM spectrum. Almost all terrestrial surfaces (except calm water) act as diffuse reflectors of incident solar radiation. The smoothness or roughness of a surface depends on the wavelength of the incident EMR.

diffuse sky radiation: Solar radiation reaching the earth's surface after having been scattered from the direct solar beam by molecules or suspensoids in the atmosphere. Also called skylight, diffuse skylight, sky radiation. Of the total light removed from the direct solar beam by scattering in the atmosphere (approximately 25 percent of the incident radiation), about two-thirds ultimately reaches the earth as diffuse sky radiation.

diffusion: The scattering of EMR upon reflection from a rough (at the wavelength of EMR) surface, or upon transmission through a translucent medium.

digital tape: A magnetic tape which records data in discrete levels, often for subsequent computer analysis.

dispersion: (l) The separation of EMR into its spectral components by its passage through a diffraction grating or by refraction such as that provided by a prism. (2) The spreading of a signal caused by variation of velocity of propagation with frequency (equivalent to non-linear phase-vs-frequency characteristics).

diurnal: Having a period of, occurring in, or related to a day.

edge enhancement: The use of analytical techniques to emphasize transition in imagery.

effective radius of the Earth: A fictitious value for the radius of the Earth, used in place of the geometrical radius to correct for atmospheric refraction. Under conditions of standard refraction, the effective radius of the Earth is 8.5×10^4 meters, or four-thirds the geometrical radius. If the effective radius is used in ray tracing diagrams, the rays may be drawn as though they were traveling in straight lines.

electromagnetic radiation (EMR): Energy propagated through space or through material media in the form of an advancing interaction between electric and magnetic fields. The term radiation, alone, is used commonly for this type of energy, although it actually has a broader meaning. Also called electromagnetic energy.

electromagnetic radiation, (coherent): EMR is coherent when it is based upon a single-frequency sinusoidal variation.

electromagnetic rockets: Plasma rockets

electromagnetic spectrum: The ordered array of known electromagnetic radiations extending from the shortest cosmic rays, through gamma rays, X-rays, ultraviolet radiation, visible radiation, infrared radiation, and including microwave and all other wavelengths of radio energy. See also absorption spectrum, continuous spectrum.

electromagnetic devices: Devices for detecting conductive bodies such as massive sulphide mineral deposits at the surface or at depths down to several hundred feet beneath the surface. They depend upon generating audio frequency electromagnetic inductive fields in coils carried by low flying aircraft, inducing eddy currents in subsurface conductive bodies and detecting the presence of these bodies by sensing the secondary field which the eddy currents re-radiate.

electronic data processing: The use of electronic devices and systems in the processing of data to manipulate data and put them into usable form as an aid to their use and interpretation.

elevation: (l) Vertical distance from the datum, usually mean sea level, to a point or object on the Earth's surface. Not to be confused with altitude, which refers to points or objects above the earth's surface. (2, architectural) An orthographic projection of any object into a vertical plane.

elliptical polarization: The polarization of a wave radiated by an electric vector rotating in a plane and simultaneously varying in amplitude so as to describe an eclipse.

emission: (l) With respect to EMR, the process by which a body emits EMR usually as a consequence of its temperature only. Compare reflection, transmission. See emittance, emissivity. (2) With respect to electric propulsion and energy conversion, the sending out of charged particles from a surface causing the generation of these particles; e.g., emission of ions from an ionizing surface in ion engines.

emission spectrum: The array of wavelengths and relative intensities of EMR emitted by a given radiator.

emissivity (symbol e): A special case of exitance, a fundamental property of a material that has a specular surface and is sufficiently thick to be opaque. One may further qualify it as spectral emissivity in reference to a specific bandpass. The suffix -ity implies a property intrinsic with a given material, a limiting value.

emittance: (1) The obsolete term for the radiant flux per unit area emitted by a body, or exitance (symbol, M; the preferred term). (2) The ratio of the emitted radiant flux per unit area of a sample to that of a black body radiator at the same temperature and under the same conditions. Spectral emittance refers to emittance measured at a specified wavelength. Because of the two common meanings of emittance, it should be defined when used unless the context allows no misinterpretation.

emulsion (photography): A suspension of a light-sensitive silver salt (especially silver chloride or silver bromide) in a colloidal medium (usually gelatin), which is used for coating photographic films, plates, and papers.

environment: An external condition or the sum of such conditions, in which a piece of equipment or a system operates, as in temperature environment, vibration environment or space environment. The environments are usually specified by a range of values, and may be either natural or artificial.

equivalent blackbody temperature: The temperature measured radiometrically corresponding to that which a blackbody would have. Most natural objects including soil, plant leaves, and water have emissivities >0.9 but <1.0.

exitance (symbol, M): The radiant flux per unit area emitted by a body or surface.

exposure: (1) The total quantity of light received per unit area on a sensitized plate or film; may be expressed as the product of the light intensity and the exposure time, in units of (for example) meter-candle-seconds or watts per square meter. (2) The act of exposing a light-sensitive material to a light source.

false color: The use of one color to represent another; for example, the use of red emulsion to represent infrared light in color infrared film.

far infrared: A term for the longer wavelengths of the infrared region, from 25 μm to 1 mm, the generally accepted shorter wavelength limit of the microwave part of the EM spectrum. This is severely limited in terrestrial use, as the atmosphere transmits very little radiation between 25 μm and the millimeter regions.

field-of-view: The solid angle through which an instrument is sensitive to radiation. Due to various effects, diffractions, etc., the edges are not sharp. In practice they are defined as the "half-power" points, i.e., the angle outwards from the optical axis, at which the energy sensed by the radiometer drops to half its on-axis value. Generally, a "2" radiometer will "see" out to 4^{o} to 5^{o} off the axis because of this diffraction effect, and should be corrected accordingly.

field stop: See aperture stop.

film: The sensitized material and its base, which is exposed in a camera.

filter: (1, noun) Any material which, by absorption or reflection, selectively modifies the radiation transmitted through an optical system. Such a filter may operate by polarization, scattering, etc., and may also be electronic. Also called wave filter. The filter usually is interposed between the film and the scene being photographed, but it may form part of the film itself. (2, verb). To remove a certain component or comonents of EMR, usually by means of a filter, although other devices may be used.

filtering: In analysis, the removal of certain spectral or spatial frequencies to highlight features in the remaining image.

focal plane (aerial photography): The plane (perpendicular to the axis of the lens) in which images of points in the object field of the lens are focused.

focus: (1) To make the camera adjustments necessary to have the focal plane of the lens and film or ground-glass coincide. (2) The point at which the rays from a point source of light reunite and cross after passing through a camera lens. In practice, the plane in which a sharp image of any scene is formed.

focus, fixed: A focus that cannot be adjusted, as in an ordinary box camera. Aerial cameras, with few exceptions, are focused at infinity and must be flown at an altitude greater than the hyperfocal distance. Fixed-focus head cameras are normally focused at the hyperfocal distance, thus permitting all objects from infinity to one-half the hyperfocal distance to be sharply defined.

frequency: Number of oscillations per unit time or number of wavelengths that pass a point per unit time. See also period. The frequency bands used by radar (radar frequency bands) were first designated by letters for military secrecy.

frequency bias: A constant frequency purposely added to the frequency of a signal to prevent the signal frequency from going to zero.

frequency response: (1) The portion of the frequency spectrum which can be sensed by a device within specified limits of amplitude error. (2) Response of a system as a function of the frequency of excitations.

frequency-shift keying: That form of frequency modulation in which the modulating wave shifts the output frequency between predetermined values, and the output wave is coherent with no phase discontinuity.

frequency swing: In frequency modulation the peak difference between the maximum and minimum values of the instantaneous frequency.

gain: (1) A general term used to denote an increase in signal power in transmission from one point to another. Gain is usually expressed in decibels. (2) An increase or amplification. In radar there are two general usages of the term: (a) antenna gain, or gain factor, is the ratio of the power transmitted along the beam axis to that of an isotropic radiator transmitting the same total power; (b) receiver gain, is the amplification given a signal by the receiver.

gamma: A numerical measure of the extent to which a negative has been developed, indicating the proportion borne by the contrast of the negative to that of the subject on which it was exposed. The numerical figure for gamma is the tangent of the straight-line (correct exposure) portion of the curve resulting from plotting exposure against density. A gamma of 1.0 indicates a negative which has greater contrast than the subject photographed.

gamma radiation: A quantum, or photon, of EMR emitted by a nucleus, each such photon being emitted as the result of a quantum transition between two energy levels of the nucleus. Gamma rays have energies usually between 10 Kev and 10 Mev, with correspondingly short wavelengths and high frequencies. Also called gamma rays.

gamma-ray spectrometer: A device for detecting gamma radiation emitted by potassium, uranium, and thorium or the daughter products of these elements which occur naturally in the earth.

giga: Prefix meaning 10^9.

gimbal: (1) A device with two mutually perpendicular and intersecting axes of rotation, thus giving free angular movement in two directions, on which an engine or other object may be mounted. (2) In a gyro a support which provides the spin axes with a degree of freedom. (3) To move a reaction engine about on a gimbal so as to obtain pitching and yawing correction moments. (4) To mount something on a gimbal.

grain (photography): (1) One of the discrete silver particles resulting from the development of an exposed light-sensitive material. (2) A lack of smoothness of the silver deposit, caused by clumps or groups of particles. Excessive graininess reduces quality, especially when magnified or enlarged.

gram (metric system): The weight of a cubic centimeter of pure water at its maximum density: It is equal to 15.432 grains avoirdupois.

granularity: The graininess of a developed photographic image, evident particularly on enlargement, that is due either to agglomerations of developed grains or to an overlapping pattern of grains.

gray body: A radiating surface whose radiation has essentially the same spectral energy distribution as that of a blackbody at the same temperature, but whose emissive power is less. Its absorptivity is nonselective. Also spelled grey body.

gray scale: A monochrome strip of shades ranging from white to black with intermediate shades of gray. The scale is placed in a setup for a color photograph and serves as a means of balancing the separation negatives and positive dye images.

Greenwich mean time (abbr. GMT): Local mean time at the Greenwich meridian; the arc of the celestial equator, or the angle at the celestial pole, between the lower branch of the Greenwich celestial meridian and the hour circle of the mean sun, measured westward from the lower branch of the Greenwich celestial meridian through 24 hours; Greenwich hour angle of the mean sun, expressed in time units, plus 12 hours. Also called universal time, Z-time. Mean time reckoned from the upper branch of the Greenwich meridian is called Greenwich astronomical time.

Greenwich meridian: The meridian through Greenwich, England, serving as the reference for Greenwich time. The Greenwich meridian is accepted almost universally as the prime meridian, or the origin of measurement of longitude.

grid line: One of the lines in a grid system; a line used to divide a map into squares. East-west lines in a grid system are x-lines, and north-south lines are y-lines.

ground data: Supporting data collected on the ground, and information derived therefrom, as an aid to the interpretation of remotely-recorded surveys, such as airborne imagery, etc. Generally, this should be performed concurrently with the airborne surveys. Data as to weather, soils and vegetation types and conditions are typical.

ground information: Information derived from ground data and surveys to support interpretation of remotely sensed data.

ground patch area: The area of terrain illuminated by the beam at any instant. Two objects located within such a terrain element will not be resolved.

ground range: (1) The distance from the ground track (nadir) to a given object.

ground range image: A sidelooking radar image in which objects at the reference elevation are located at distances corresponding to their separation on the terrain.

ground speed: The rate of motion of an aircraft or space vehicle along its track with relation to the ground: The resultant of the heading and air speed of an aircraft and the direction and velocity of the wind.

ground track: The vertical projection of the actual flight path of an aerial or space vehicle onto the surface of the earth or other body.

ground truth (jargon): Term coined for data/information obtained on surface/subsurface features to aid in interpretation of remotely sensed data. A vague, misleading term suggesting that the truth may be found on the ground. Ground data and ground information are preferred terms.

Hertz (abbr. Hz): The unit of frequency, cycles per second.

highlights: (1) Those portions of a subject from which the greatest amounts of light are reflected. (2) The densest parts of a negative and the lightest parts of a print or transparency. (3, television) The maximum brightness of the picture, which occurs in regions of highest illumination.

high oblique: An oblique photo which shows the horizon line.

hiran: An electronic distance-measuring system similar to shoran, but with improved accuracy, for measuring distance from an airborne station to each of two ground stations. The term hiran is a contraction of high-precision shoran.

horizon: In general, the apparent or visible junction of earth and sky, as seen from any specific position. Also called the apparent, visible, local, or sensible horizon, true horizon: A horizontal plane passing through a point of vision or a perspective center. The apparent or visible horizon approximates the true horizon only when the point of vision is very close to sea level.

horizontal blanking: The blanking signal at the end of each scanning line of a CRT.

horizontal retrace: The return of the electron beam from the right to the left side of the raster after scanning one line of a CRT.

hue: That attribute of a color by virtue of which it differs from gray of the same brilliance, and which allows it to be classed as red, yellow, green, blue, or intermediate shades of these colors.

humidity: Degree of wetness, especially of the atmosphere, relative humidity: Ratio of water vapor present, at a given temperature, to the greatest amount possible at the temperature. Absolute humidity: The weight of water vapor contained in a given volume of air, in grains per cu. ft. or grams per cu. meter. Specific humidity: The weight of water vapor per unit weight of the moist air.

illumination: The intensity of light striking a unit surface is known as the specific illumination or luminous flux. It varies directly with the intensity of the light source and inversely as the square of the distance between the illuminated surface and the source. It is measured in a unit called the lux. The total illumination is obtained by multiplying the specific illumination by the area of the surface when the light strikes. The unit of total illumination is the lumen.

image: (1) The counterpart of an object produced by the reflection or refraction of light when focused by a lens or mirror.

image: (2) The recorded representation of an object produced by optical, electro-optical, optical mechanical, or electronic means. It is generally used when the EMR emitted or reflected from a scene is not directly recorded on film.

image, ghost: The reflection of light from a bright subject by the elements of the lens or its mounting to form a spurious image.

image, latent: The invisible image, recorded by light action upon the film or plate, which is made visible in development.

image enhancement: The manipulation of image density to more easily see certain features of the image.

imagery: The products of image-forming instruments (analogous to photography).

impedance: In an a-c electric circuit, the combined effect of circuit resistance and reactance.

incandescence: Emission of light due to high temperature of the emitting material. Any other emission of light is called luminescence.

inch (abbr. in.): Exactly 2.540 centimeters.

incidence: (1) Partial coincidence, as a circle and a tangent line. (2) The impingement of a ray on a surface.

incident ray: A ray impinging on a surface.

index of absorption: Absorptive index.

index of refraction (symbol n): (1) A measure of the amount of refraction (a property of a dielectric substance). It is the ratio of the wavelength or phase velocity of EMR in a vacuum to that in the substance. Also called refractive index, absolute index of refraction, absolute refractive index, refractivity. It can be a function of wavelength, temperature, and pressure.

infrared (abbr. IR): Pertaining to or designating the portion of the EM spectrum with wavelengths just beyond the red end of the visible spectrum, such as radiation emitted by a hot body (see infrared radiation).

infrared line scanner: See scanner, scanning radiometer.

infrared, photographic: (1) Pertaining to or designating the portion of the EM spectrum with wavelengths just beyond the red end of the visible spectrum, such as radiation emitted by a hot body (over 500° C); generally defined as from 0.7 to about 1.0 μm, or the useful limits of film sensitivities.

infrared radiation: EMR in the wavelength interval from about 0.75 μm to 1 mm. Also called long wave radiation. At its lower limit, infrared radiation spectrum is bounded by visible radiation, and on its upper limit by microwave radiation.

instantaneous field-of-view: (IFOV): (1) A term specifically denoting the narrow field of view designed into scanning radiometer systems, so that, while about 120° may be under scan, at any one instant only EMR from a small area is being recorded. (2) The field of view of a scanning radiometer with the scan motion stopped. See field of view, cell.

instrument: (1, noun) A device that measures, detects, or otherwise performs to provide information about quantities or conditions. (2, verb) to provide a vehicle or component with instrumentation.

instrumentation: (1) The installation and use of electronic, gyroscopic, and other instruments for the purpose of detecting, measuring, recording, telemetering, processing, or analyzing different values or quantities as encountered in the flight of a rocket or spacecraft. (2) The assemblage of such instruments in an aircraft, rocket, spacecraft, other vehicle or place. (3) A special field of engineering concerned with the design, composition and arrangement of such instruments.

irradiation: (1) The impinging of EMR on an object or surface. (2) The spreading of light in an emulsion caused by reflection from the surfaces of the silver halide crystals. The slight blurring caused by irradiation should not be confused with the more noticeable and extensive blurring known as halation, which is caused by reflection from the back surface of the plate or film on which the emulsion is supported.

isotropic radiation: Diffuse radiation that has exactly the same intensity in all directions. This should not be called perfectly diffuse radiation because of the likelihood of confusion with the concept of a perfectly diffuse radiator.

joule (abbr. j): A unit of energy or work in the MKS system; the work done when the point of application of 1 newton is displaced a distance of 1 meter in the direction of the force.

$$1 \text{ joule} = 10^7 \text{ ergs} = 1 \text{ watt second.}$$

Joule constant: The ratio between heat and work units from experiments based on the first law of thermodynamics:

$$4.1858 \times 10^7 \text{ ergs per } 15^\circ \text{ calorie.}$$

Also called mechanical equivalent of heat.

Kelvin: A thermometer scale starting at absolute zero ($-273\,^\circ C$ approximately) and having degrees of the same magnitude as those of the Celsius thermometer. Thus $0^\circ C = 273^\circ K$; $100^\circ C = 373^\circ K$; etc.; also called the absolute scale, thermodynamic temperature scale.

key, photo-interpretation: A device designed to aid in the rapid, accurate identification of an object and in judging its significance from its appearance in a picture.

Kirchoff's Law: The radiation law which states that at a given temperature the ratio of the emissivity to the absorptivity for a given wavelength is the same for all bodies and is equal to the emissivity of an ideal black body at that temperature and wavelength. This important law asserts that good absorbers of a given wavelength are also good emitters of the wavelength: It is essential to note that Kirchoff's law relates absorption and emission at the same wavelength and at the same temperature. Also called Kirchoff's radiation law.

large-scale: (1) Aerial photography with a representative fraction of 1:500 to 1:10,000. (2) Maps with a representative fraction (scale) greater than 1:100,000.

laser: (From light amplification by stimulated emission of radiation). A device for producing light by emission of energy stored in a molecular or atomic system when stimulated by an input signal.

latent image: An invisible image produced by the physical or chemical effect of light upon matter (usually silver halide or halides), which can be rendered visible by the subsequent chemical process of photographic development.

lateral chromatic aberration: A lens aberration that affects the sharpness of images off the axis because different colors undergo different magnifications.

latitude: (1, photography; exposure) The quality of a film or plate indicating the variation in exposure which can be tolerated without detriment to image quality. (2, photography; development) Allowable variation in the recommended development time without appreciable difference in contrast. (3) Angular distance north or south of the Equator measured along a meridian.

layover: Displacement of the top of an elevated feature with respect to its base on the radar image. The peaks look like dip-slopes.

leader: A strip of film at the beginning of a roll of film which is used for loading the camera.

lens: A piece, or combination of pieces (elements) of glass or other transparent material shaped to form an image by means of refraction; an integral part of all but the simplest cameras.

line frequency: The number of horizontal scans per second; 15,750 times per second for standard television in the U.S.A.

light: Visible radiation (about 0.4 to 0.7 um in wavelength) considered in terms of its luminous efficiency; i.e., evaluated in proportion to its ability to stimulate the sense of sight.

line, flight: A line drawn on a map or chart to represent the track over which an aircraft has been flown or is to fly. The line connecting the principal points of vertical aerial photographs.

lithosphere: The solid part of the Earth or other spatial body. Distinguished from the atmosphere and the hydrosphere.

lumen: A unit of luminous flux equal to the luminous flux radiated into a unit solid angle (steradian) from a point source having a luminous intensity of 1 candela. An ideal source possessing an intensity of 1 candela in every direction would radiate a total of 4π lumens.

luminance: In photometry, a measure of the intrinsic luminous intensity emitted by a source in a given direction; the illuminance produced by light from the source upon a unit surface area oriented normal to the line of sight at any distance from the source, divided by the solid angle subtended by the source at the receiving surface. Also called brightness (luminance is preferred). Compare luminous intensity. It is assumed that the medium between source and receiver is perfectly transparent; therefore luminance is independent of extinction between source and receiver. The source may or may not be self-luminous. Luminance is a measure only of light; the comparable term for EMR in general is radiance.

luminescence: Light emission by a process in which kinetic heat energy is not essential for the mechanism of excitation. Electroluminescence is the production of light emission in a solid phosphor by the application of an electric field. This field stimulates electron or ion collision which causes the energy of electrons or ions to be given up, resulting in light emission. Chemiluminescence results when energy, set free in a chemical action, is converted to light energy. The light from many chemical reactions and from many flames is of this type. Photoluminescence, or fluorescence, results from excitation by absorption of light. The term phosphorescence is usually applied to luminescence which continues after excitation by one of the above methods has ceased. Compare incandescence.

luminous intensity: Luminous energy per unit time per unit solid angle: The intensity (flux per unit solid angle) of visible radiation weighted to take into account the variable response of the human eye as a function of the wavelength of light. Usually expressed in candelas. Also called candlepower, light intensity, Compare luminance.

macroscopic: Large enough to be visible to the naked eye or under low order of magnification.

magnification (Optics): The ratio of the size of an image to the size of the object, normally the ratio of a linear quantity in the image to a corresponding linear quantity in the object.

main bang (jargon): Within a radar system, the transmitted pulse.

map: A representation in a plane surface, at an established scale, of the physical features (natural, artificial, or both) of a part of all of the earth's surface with the means of orientation indicated. Also, similar representation of certain features to satisfy specific requirements. Frequently the word "map" is preceded by an adjective which explains what type of information the map is designed primarily to present. Many types and scales of maps are made to serve numerous purposes.

map grid: Two sets of parallel lines at right angles drawn on a plane surface and used as a rectangular coordinate system (a reference system) for plotting position and scaling distances and directions in surveying and mapping. A map grid may or may not be based on a map projection.

map, large-scale: A map having a scale of 1/1000,000 or larger.

map, medium-scale: A map having a scale from 1/100,000, exclusive, to 1/1,000,000, inclusive.

map, small-scale: A map having a scale smaller than 1/1,000,000.

marginal information: The notations printed in the margins or borders of mosaics, plans, or especially maps.

mark, floating: A mark seen as occupying a position in the three-dimensional space formed by the stereoscopic fusion of a pair of photographs used as a reference mark in examining or measuring the stereoscopic model.

mark, index: A real mark, such as a cross or a dot, lying in the plane or object space of a photograph and used singly or as one of a pair to form a floating mark, as in certain types of stereoscopes.

marks, static: Marks on a negative caused by discharges of static electricity, particularly when the unexposed negatives are handled rapidly under dry conditions.

mean sea level (MSL): The average level of the sea, as calculated from a large number of observations taken at equal intervals of time.

medium scale: (1) Aerial photographs with a representative fraction of 1:12,000 to 1:30,000. (2) Maps with a representative fraction (scale) of 1:100,000 to 1:1,000,000.

mega (M): A prefix meaning multiplied by one million as in "megacycles".

megacycle (Mc): One million cycles; one thousand kilocycles. The term is often used erroneously as the equivalent of one million cycles per second or megahertz (MHz).

meterology: The study dealing with the phenomena of the atmosphere. This includes not only the physics, chemistry, and dynamics of the atmosphere, but is extended to include many of the direct effects of the atmosphere upon the earth's surface, the oceans, and life in general. A distinction can be drawn between meterology and climatology, the latter being primarily concerned with average, not actual, weather conditions. Meterology may be subdivided, according to the methods of approach and the applications to human activities, into a large number of specialized sciences. The following are of interest or use to remote sensing: aerology, astronomy, dynamic meteorology, physical meteorology, radio meteorology.

meter: (1) (abbr. m) The basic unit of length of the metric system, defined as 1,650,763.73 wavelengths in vacuo of the unperturbed transition $2p_{10}$-5d in Krypton μ. Effective 1 July 1959 in the U.S. customary system of measures, 1 yard = 0.9144 meter, exactly, or 1 meter = 1.094 yards = 39.37 inches. The standard inch is exactly 25.4 millimeters. (2) A device for measuring, and usually indicating, some quantity.

metric system: The international standard system of weights and measures. The meter, kilogram, and second are the fundamental units of measures of length, mass, and time, respectively.

mil: (1) One-thousandth of an inch. (2) A unit of angular measurement, 1/6400 of a circle.

mile: A unit of distance, equal to 1,609.344 m. Also called statute mile; compare nautical mile.

milli (abbr. m): A prefix meaning 10^{-3}.

millibar: A unit of pressure equal to 1000 dynes per square centimeter, or 1/1000 of a bar. The millibar is used as a unit of measure of atmospheric pressure, a standard atmosphere being equal to 1,013.25 millibars or 29.92 inches of mercury.

milligal: A unit of acceleration equal to 1/1000 of a gal. or 1/1000 centimeter per second per second. This unit is used in gravity measurements, being approximately one-millionth of the average gravity at the earth's surface.

millimeter (abbr. mm): One-thousandth of a meter; one-tenth of a centimeter; 0.039370 U.S. inch.

millimicron (abbr. mμ): A former unit equal to 10^{-9} m; redesignated nanometer under the "International System of Units."

microdensitometer: A special form of densitometer for reading densities in very small areas; used for studying astronomical images, spectroscopic records, and for measuring image edge gradients and graininess in films.

micrometer (abbr. μm): A unit of length equal to one-millionth (10^{-6}) of a meter or one-thousandth (10^{-3}) of a millimeter.

micron (abbr. μ): Equivalent to and replaced by micrometer; 10^{-6}m.

microphotography: The reproduction of text or pictures at ratios of reduction too great for reading or viewing without optical assistance.

microwave: A very short EM wave; any wave between 1 meter and 1 millimeter in wavelength or 300 GHz to 0.3 GHz in frequency. The portion of the electromagnetic spectrum in the millimeter and centimeter wavelengths, bounded on the short wavelength side by the far infrared (at 1 mm) and on the long wavelength side by very high-frequency radio waves. Passive systems operating at these wavelengths sometimes are called microwave systems. Active systems are called radar, although the literal definition of radar requires a distance-measuring capability not always included in active systems. The exact limits of the microwave region are not defined.

mosaic: An assemblage of overlapping aerial or space photographs or images whose edges have been matched to form a continuous pictorial representation of a portion of the earth's surface.

mosaic, controlled: A mosaic which is laid to ground control and in which prints are used which have been ratioed and rectified as shown to be necessary by the control.

mosaic, semi-controlled: A mosaic composed of corrected or uncorrected prints laid to a common basis of orientation other than ground control.

mosaic, strip: A mosaic consisting of one strip of photographs or images taken on a single flight.

mosaic, uncontrolled: A mosaic composed of uncorrected prints, the detail of which has been matched from print to print without ground control or other orientation.

mosaicking: The assembling of photographs or other images whose edges are cut and matched to form a continuous photographic representation of a portion of the earth's surface.

multiband system: A system for simultaneously observing the same (small) target with several filtered bands, through which data can be recorded. Usually applied to cameras, may be used for scanning radiometers which utilize dispersant optics to split wavelength bands apart for viewing by several filtered detectors.

multi-channel system: Usually used for scanning systems capable of observing and recording several channels of data simultaneously, preferably through the same aperture.

multi-lens camera: (1) A camera having two or more lenses pointing at the same target which, when used with different film/filter combinations, produces multiband photographs. (2) A camera having two or more lenses pointed at an angle to one another, and taking two or more overlapping pictures simultaneously.

multispectral: Generally used for remote sensing in two or more spectral bands, such as visible and IR.

multispectral (line) scanner: A remote sensing device which operates on the same principle as the infrared scanner except that it is capable of recording data in the ultraviolet and visible portions of the spectrum as well as the infrared.

nadir: (1) That point on the celestial sphere vertically below the observer, or 180° from the zenith. (2) That point on the ground vertically beneath the perspective center of the camera lens.

nautical chart: A map especially designed for the mariner, on which are shown navigable waters and the adjacent or included land, if any, and on which are indicated depths of water, marine obstructions, aids to navigation and other pertinent information. Also called hydrographic chart.

nautical mile (abbr. knot): A unit of distance used principally in navigation. For practical navigation it is usually considered the length of 1 minute of any great circle of the earth, the meridian being the great circle most commonly used. Also called sea mile. Because of various lengths of the nautical mile in use throughout the world, due to differences in definition and the assumed size and shape of the earth, the International Hydrographic Bureau in 1929 proposed a standard length of 1852 meters, which is known as the International nautical mile.

near infrared: The preferred term for the shorter wavelengths in the infrared region extending from about 0.7 micrometers (visible red), to around 2 or 3 micrometers (varying with the author). The longer wavelength end grades into the middle infrared. The term really emphasizes the radiation reflected from plant materials, which peaks around 0.85 micrometers. It is also called solar infrared, as it is only available for use during the daylight hours.

negative: (1) A photographic image on film, plate, or paper, in which the tones are reversed. (2) A film, plate, or paper containing such a reversed image.

negative, color: (1) A photographic image on film, plate, or paper, in which the colors appear as the complements of those in nature. (2) A film, plate or paper containing such an image.

oblique photograph: A photograph taken with the camera axis intentionally directed between the horizontal and the vertical. A high-oblique photograph is one in which the apparent horizon is included within the field of view, whereas a low-oblique photograph does not include the apparent horizon within the field of view.

overlap: The area common to two successive photos along the same flight strip; the amount of overlap is expressed as a percentage of photo area. Also called endlap.

overlay: (1) A transparent sheet giving information to supplement that shown on maps. When the overlay is laid over the map on which it is based, its details will supplement the map. (2) A tracing of selected details on a photograph, mosaic, or map to present the interpreted features and the pertinent detail.

panchromatic: Used for films that are sensitive to broad band(e.g., entire visible part of spectrum) EMR, and for broadband photographs.

panorama: A photograph of a wide expanse of terrain, normally taken on or near the earth's surface; more often a series of adjoining or overlapping photographs.

parabola: A mathematical curve, one of the conic sections, whose importance to EMR is that a parabolic reflector with a point source of EMR placed at its focus.

parallax: The apparent change in the position of one object, or point, with respect to another, when viewed from different angles. As applied to aerial photos, the term refers to the apparent displacement of two points along the same vertical line when viewed from a point (the exposure station) not on the same vertical line.

passive: Applied to EMR emitted from an object or surface; also used for reflected natrual EMR. Compare active.

passive system: A sensing system that detects or measures radiation emitted by the target. Compare active system.

pattern: (1) In a photo image, the regularity and characteristic placement of tones or textures. Some descriptive adjectives for patterns are regular, irregular, random, concentric, radial, and rectangular. (2) The relations between any more-or-less independent parameters of a response e.g., the pattern in the frequency domain of the response from an object.

pattern recognition: See pattern.

perigee: That orbital point nearest the body about which a satellite is orbiting.

perihelion: For an elliptic orbit about the Sun, the point closest to the Sun.

period: Time required for one oscillation. Thus it is the reciprocal of the frequency.

pH: A symbol expressing the degree of acidity or alkalinity of a solution. It is equal to the logarithm of the reciprocal of the hydrogen ion concentration (LOG 1/H). A neutral solution (pure water) has a pH of 7.0 while alkaline solutions have a higher pH and acid solution a lower pH.

photoelectric cell: A transducer which converts electromagnetic radiation in the infrared, visible, or ultraviolet regions into electrical quantities such as voltage, current, or resistance. Also called photocell.

Photoelectric effect: The emission of an electron from a surface as the surface absorbs a photon of EMR.

photogrammetry: The art or science of obtaining reliable measurements by means of photography.

photograph: A picture formed by the action of light on a base material coated with a sensitized solution which is chemically treated to fix the image points at the desired density. Usually now taken to mean the direct action of EMR on the sensitized material. Compare image.

photograph, composite: A photograph made by assembling the separate photographs made by each lens of a multiple lens camera in a simultaneous exposure into the equivalent of a photograph taken with a single wide-angle lens.

photograph, horizon: A photograph of the horizon taken simultaneously with another photograph for the purpose of obtaining an indication of the orientation of the other photograph at the instant of exposure.

photograph, multiple-lens: A photograph made with a camera having two or more lenses. See multiple-lens camera (2).

photograph, radar scope: A photograph of the cathode tube of a radar set, taken to record the radar return displayed thereon. Radar image is preferred.

photograph, split-vertical: Photographs taken simultaneously by two cameras mounted at an angle from the vertical, one tilted to left and one to right, to obtain a small side-lap.

photograph, wing: A photograph taken by one of the side or wing lenses of a multiple lens camera.

photographic interpretation: The act of examining photographic images for the purpose of identifying objects and judging their significance. Photo interpretation, photointerpretation, and image interpretation are other widely used versions.

photometer: An instrument for measuring the intensity of light or the relative intensity of a pair of lights. Also called illuminometer. If the instrument is designed to measure the intensity of light as a function of wavelength, it is called a spectrophotometer.

Planck's law: An expression for the variation of monochromatic emittance (emissive power) as a function of wavelength of black-body radiation at a given temperature; it is the most fundamental of the radiation laws.

processing: (1) The operation necessary to produce negatives, diapositives, or prints from exposed film, plates, or papers. (2) The manipulation of data by means of computer or other device.

propagation: Propagation refers to the combination of all processes other than absorption which take place when radiant energy falls on a body; it is the sum of a reflection (specular and diffuse) and transmission.

radar: Acronym for radio detection and ranging. A method, system or technique, including equipment components, for using beamed, reflected, and timed EMR to detect, locate, and (or) track objects, to measure altitude and to acquire a terrain image. In remote sensing of the Earth's or planetary surface, it is used for measuring, and often, mapping the scattering properties of the surface.

radar beam: The vertical fan-shaped beam of EM energy produced by the radar transmitter.

radar mile: A time unit of 10.75 microseconds duration; the time it takes for the signal emitted by a radar to travel from the radar to a target one mile distant and return to the radar.

radar reflectivity: In general, the measure of the efficiency of a radar target in interpreting and returning a radar signal. It depends upon the size, shape, aspect, and the dielectric properties at the surface of the target. It includes the effects of not only reflection (see reflectivity) but also scattering and diffraction.

radiance: The accepted term for radiant flux in power units (e.g. watts) and not for flux density per solid angle (e.g., watts/cm^{2}sr) as often found in recent publications.

radiancy: Radiancy denotes emitted radiant flux density, measured as power per unit area (e.g., watts/cm^2).

radiant power: Rate of change of radiant energy with time. May be further qualified as spectral radiant power, at a given wavelength.

radiation: The emission and propagation of energy through space or through a material medium in the form of waves; e.g., the emission and propagation of EM waves, or of sound and elastic waves. The process of emitting radiant energy.

radiometer: An instrument for quantitively measuring the intensity of EMR in some band of wavelengths in any part of the EM spectrum. Usually used with a modifier, such as IR radiometer or microwave radiometer. Most radiometers measure the difference between the source radiation incident on the detector and a radiant energy (blackbody) reference. Comparison between the two is often achieved by mechanically interposing a reflective chopper, so that both sources can be viewed consecutively by the same detector, or by electrically switching, as in a microwave radiometer.

Rayleigh-Jeans Law: An approximation to Planck's Law for blackbody radiation valid in the longer (microwave) wavelengths. It is almost always of sufficient accuracy for calculations in the radio and microwave regions of the spectrum.

real time: Time in which reporting on events or recording of events is simultaneous with the events. For example, the real time of a satellite is that time in which it simultaneously reports its environment as it encounters it; the real time of a computer is that time during which it is accepting data and performing operations on it.

reflectance: The ratio of the radiant energy reflected by a body to that incident upon it. The suffix (-ance) implies a property of that particular specimen surface.

reflection (EMR theory): EMR neither absorbed nor transmitted is reflected. Reflection may be diffuse when the incident radiation is scattered upon being reflected from the surface, or specular, when all or most angles of reflection equal the angle of incidence.

reflectivity: A fundamental property of a material that has a reflecting surface and is sufficiently thick to be opaque. One may further qualify it as spectral reflectivity. The suffix (-ity) implies a property intrinsic with a given material, a limiting value.

refraction: The bending of EMR rays when they pass from one medium into another

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having a different index of refraction or dielectric coefficient. EMR rays also bend in media that have continuous variations in their indices of refraction or dielectric coefficients.

relativity: A principle that postulates the equivalence of the description of the universe, in terms of physical laws, by various observers, or for various frames of reference.

remote sensing: (1) In the broadest sense, the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study; e.g., the utilization at a distance (as from aircraft, spacecraft, or ship) of any device and its attendant display for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy. The technique employs such devices as the camera, lasers, and radio frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, and scintillation counters. (2) The practice of data collection in the wavelengths from ultraviolet to radio regions. This restricted sense is the practical outgrowth from airborne photography. Sense (1) is preferred and thus includes regions of the EM spectrum as well as techniques traditionally considered as belonging to conventional geophysics. Also called rapid reconnaissance. French: teledetection; German: fernerkundung; Portuguese: sensoriamento remoto; Russion: distantsionnaya; Spanish: perception remota.

resolution: The ability of an entire remote sensor system, including lens, antennae, display, exposure, processing, and other factors, to render a sharply defined image. It may be expressed as line pairs per millimeter or meters, or in many other manners. In radar, resolution usually applies to the effective beamwidth and range measurement width, often defined as the half-power points. For infrared line scanner scanners the resolution may be expressed as the instanteous field-of-view. Resolution also may be expressed in terms of temperature or other physical property being measured.

return beam vidicon (RBV): A modified vidicon television camera tube, in which the output signal is derived from the depleted electron beam reflected from the tube target. The RBV can be considered as a cross between a vidicon and an orthicon. RBV's provide highest resolution TV imagery, and are used in the ERTS (LANDSAT) series.

satellite: An attendant body that revolves about another body, the primary; especially in the solar system, a secondary body, or moon, that revolves about a planet. A man-made object that revolves about a spacial body.

saturation: Degree of intensity difference between a color and an acromatic light-source color of the same brightness.

scale: (1) The full range of tones of which a photographic paper is capable of reproducing is called the scale of the paper, it is also termed dynamic range. (2) The ratio of a distance on a photograph or map to its corresponding distance on the ground. The scale of a photograph varies from point to point because of displacements caused by tilt and relief, but is usually taken as f/H where f is the principal distance (focal length) of the camera and H is the height of the camera above mean ground elevation. Scale may be expressed as a ratio, 1:24,000; a representative fraction, 1/24,000; or an equivalence, 1 in. = 2,000 ft.

scale, graphic: A graduated line on the margin of a map, chart, mosaic, etc., by means of which scaled distances may be measured in terms of actual ground distances. Also called bar scale.

scale, gray: A term used to describe the various tonal graduations on a photographic medium, cathode ray tube, or other display medium or device.

scale height: A measure of the relationship between density and temperature at any point in an atmosphere; the thickness of a homogeneous atmosphere which would give the observed temperature or pressure.

scale, tree crown: A simple measuring device printed on a transparent templet for measuring diameters of tree crowns and dimensions of other small objects. It may be designed in the form of a micrometer wedge or with small circular dots of graduated sizes.

scanners: (l) Any device that scans, and by this means produced an image. See scanning radiometer. (2) A radar set incorporating a rotatable antenna, or radiator element, motor drives, mounting, etc. for directing a searching radar beam through space and imparting target information to an indicator.

scanning: (l) The sweep of a mirror, prism, antenna, or other element across the track (direction of flight); may be straight, circular, or other shape. (2, radar) The motion of the radar antenna assembly when searching for targets.

scanning radiometer: A radiometer, which by the use of a rotating or oscillating plane mirror, can scan a path normal to the movement of the radiometer. The plane mirror may move in various patterns-arcs, circles, lines. The mirror directs the incoming radiation to a detector, which converts it into a electrical signal. This signal is amplified to stimulate a device such as a tape recorder, or glow tube or CRT that can be photographed to produce a picture. When the system is moved forward at velocity V and at altitude H, a suitable V/H ratio may be established, so that consecutive scans are just touching. This is often called an IR-imager, but is only so restricted because of the optical materials used, all-reflective optics being as useful in the UV and visible regions. They may all be single-or multiple-band.

scanning radiometer (microwave): A passive microwave radiometer that produces an image by mechanically or electronically scanning its antenna beam.

scatter, isotropic: A theoretical device that, after intercepting a given amount of energy, reradiates it equally in all directions.

scattering: (l) The process by which small particles suspended in a medium of a different index of refraction diffuse a portion of the incident radiation in all directions. (2) The process by which a rough surface reradiates EMR incident upon it.

scatterometry: A method of using radar to measure the variation of radar scattering coefficient. These variations may be used by geoscientists to discriminate between surfaces with different roughness and materials. The scatterometer is distinguished from other radars by its ability to measure amplitude.

scintillation: Effect that can cause loss of returns because of interference of signals from different objects within the same resolvable element causes large random amplitude variation.

scintillation detector: A remote sensing device built to detect gamma radiation with energy levels greater than 50 Kev (thousand electron volts).

sensitivity, color: The sensitivity of a photographic emulsion to light of various wave lengths.

sensitometer: An instrument which exposes a photographic film in a known manner so that its light-sensitive properties may be measured.

sensitometry: The measurement of the sensitivity and other photographic characteristics of photographic materials.

sensor: Any device which gathers energy EMR or other and presents it in a form suitable for obtaining information about the environment. Passive sensors, such as thermal infrared and microwave, utilize EMR produced by the surface or object being sensed. Active sensors, such as radar, supply their own energy source. Aerial cameras use natrual or artifically produced EMR external to the object or surface being sensed.

sidereal day: A day as measured by sidereal time. A sidereal day begins and ends when the first point of Aries is directly over the reference meridian. Because of the motion of the earth around the sun, a sidereal day is almost 4 minutes shorter than the solar day.

sidereal time: Time measured by the rotation of the earth with respect to the stars.

signature: Any characteristic or series of characteristics by which a material may be recognized. Used in the sense of spectral signature, as in photographic (color reflectance.

signature analysis techniques: Techniques which use the variation in the spectral reflectance or emittance of objects as a method of identifying the objects.

smoothing: The averaging of densities in adjacent areas to produce more gradual transitions.

spatial resolution: see resolution.

spectral band: An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

spectral colors: The continuous band of pure colors in the visible spectrum are divided, for convenience, into seven basic spectral colors: violet, indigo, blue, green, yellow, orange, and red.

spectral interval: The width, generally expressed in wavelength or frequency of a particular portion of the electromagnetic spectrum. A given sensor (e.g. radiometer detector or camera film) is designed to measure or be sensitive to energy received at the satellite from that part of the spectrum. Also termed spectral band.

spectral signature: Quantitative measurement of the properties of an object at one or several wavelength intervals.

spectral-zonal: See multiband system, the preferred term.

spectogram: A photograph of a spectrum, which permits a study of the absorption and transmission properties of the material from which the spectrum was taken. Used for the study of filters; a scale on the spectrogram shows the relative amount of transmission of various colors (or wavelengths) through a particular filter.

spectrometer: A device to measure the spectral distribution of EMR. This may be achieved by a dispersive prism, grating, circular interference filter with a detector placed behind a slit. If one detector is used, the dispersive element is moved as to sequentially pass all dispersed wavelengths across the slit. In an inteferometer-spectrometer, on the other hand, all wavelengths are examined all the time, the scanning effect being achieved by rapidly oscillating two, partly reflective, (usually parallel) plates so that interference fringes are produced. A Fourier transform is required to reconstruct the spectrum. Also called spectroradiometer.

spectrophotometer: A photometer which measures the intensity of EMR as a function of the frequency (or wavelengths) of the EMR. Usually used for the visible portion. See spectrometer; also called spectroradiometer.

spectrum: (1) In physics, any series of energies arranged according to wavelength (or frequency). (2) The series of images produced when a beam of radiant energy is subject to dispersion. A rainbow-colored band of light is formed when white light is passed through a prism or a diffraction grating. This band of colors results from the fact that the different wavelengths of light are bent in varying degrees by the dispersing medium and is evidence of the fact that white light is composed of colored light of various wavelengths.

spectrum, electromagnetic: See electromagnetic spectrum.

speed, ground: The velocity of an aircraft along its track with relation to the gound; the resultant of the heading and air speed of an aircraft and the direction and velocity of the wind.

stationary orbit: An orbit in which an equatorial satellite revolves about the primary at the same angular rate as the primary rotates on its axis. From the primary, the satellite thus appears to be stationary over a point on the primary.

Stefan-Boltzmann Law: One of the radiation laws; it states that the amount of energy radiated per unit time from a unit surface area of an ideal black body is proportional to the fourth power of the absolute temperature of the black body.

steradian: The unit solid angle which cuts unit area from the surface of a sphere of unit radius centered at the vertex of the solid angle. There are 4π steradians in a sphere.

stereoscope: A binocular optical instrument for assisting the observer to view two properly oriented photographs or diagrams to obtain the mental impression of a three-dimensional model.

stereoscopic image: That mental impression of a three-dimensional object which results from stereoscopic vision (stereoviewing).

strip: Any number of photos taken along a photo flight line, usually at an approximately constant altitude.

strip camera: See strip.

subtractive color process: A method of creating essentially all colors through the subtraction of light of the 3 subtractive color primaries(cyan, magenta and yellow) in various proportions through use of a single white light source.

synchronous satellite: An equatorial west-to-east satellite orbiting the earth at an altitude of 34,900 km at which altitude it makes one revolution in 24 hours synchronous with the earth's rotation.

target: (1) The distinctive marking or instru-

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mentation of a ground point to aid in its identification on a photograph. In photogrammetry, target designates a material marking so arranged and placed on the ground as to form a distinctive pattern over a geodetic or other control-point marker on a property corner on line, or at the position of an identifying point above an underground facility or feature. (2) In radar, an object returning a radar echo to the receiver.

telemetry: The science of measuring a quantity orquantities, transmitting the measured value to a distant station, and there interpreting, indicating, or recording the quantities measured, telemetry link: The system for transmitting data over long distances using radio techniques.

thermal band: A general term for middle-infrared wavelengths which are transmitted through the atmosphere window at 8-13 micrometers. Occasionally also used for the windows around 3-6 micrometers.

thermal infrared: The preferred term for the middle wavelength range of the IR region, extending roughly from 3 micrometers at the end of the near infrared, to about 15 or 20 micrometers where the far infrared commences. In practice the limits represent the envelope of energy emitted by the earth behaving as a greybody with a surface temperature around 290°K (27°C). Seen from any appreciable distance, the radiance envelope has several brighter bands corresponding to windows in the atmospheric absorption bands. The thermal band most used in remote sensing extends from 8-13 micrometers.

tilt: The angle between the optical axis of the camera and the plumb line for a given photo.

tilt, x-and y: Tilt expressed as resultant rotations about each of two stationary rectangular axes lying in a horizontal plane and the x-tilt being the resultant rotation about the x-axis and the y-tilt the resultant rotation about the y-axis. In an aircraft, the x-axis is the longitudinal axis of the aircraft, lengthwise through the fuselage; the y-axis is the transverse axis, from wingtip to wingtip.

time, Greenwich mean: Mean solar time of the meridian of Greenwich, England, used by most navigators and adopted as the prime basis of standard time throughout the world.

translucent: Semi-transparent. A substance is translucent if it allows light to pass through it, but interferes enough with the passage of light to diffuse it to a large degree. Ground and opal glass, and thin paper, are translucent.

transmission: The amount of radiation of different wavelengths which a filter, lens, or film will transmit. Also called spectral transmission.

transmission loss: (1) The loss of light in transmission through good optical glass. Approximately 2.4 percent of visual light is lost for every centimeter of glass traversed. (2) The loss of radio strength between transmitting antenna and receiving antenna.

transmissivity: Transmittance for a unit thickness sample. One may further [illegible] quAlify it as spectral transmissivity. The suffix (-ity) infers a property intrinsic with a given material.

transmittance: The ratio of the radiant energy transmitted through a body to that incident upon it. The suffix (-ance) infers a property of that particular specimen.

transparency: The light-transmitting capability of a material. The loss of light in transmission through good optical glass. Approximately 2.4 percent of visual light is lost for every centimeter of glass traversed. (2) A positive image upon glass or film, intended to be viewed by transmitted light, either black and white or in color; also called a diapositive.

ultraviolet radiation: EMR of shorter wavelength than visible radiation but longer than X-rays; roughly, radiation in the wavelength interval between 10 and 4000 A.

uncontrolled mosaic: A mosaic made without correction for distortion of any type.

vidicon: (1) A storage-type electronically scanned photoconductive televison camera tube, which often has a response to radiations beyond the limits of the visible region. Particularly useful in space applications, as no film is required. (2) An image-plane scanning device. See return beam vidicon.

viewfinder: (1) A camera attachment which shows on a viewing lens the image thrown by the camera lens on the photographic plate. (2) An aerial sighting instrument with a grid of cross-hairs on a groundglass screen, usually mounted behind the camera in a photographic plane.

wavelength (symbol λ): Wavelength = velocity/frequency. In general, the mean distance between maximums (or minimums) of a roughly periodic pattern. Specifically, the least distance between particles moving in the same phase of oscillation in a wave disturbance. Optical and IR wavelengths are measured in nanometers (10^{-9} m), micrometers (10^{-6} m) and Angstroms (10^{-10} m).

white: An object is said to be white if it reflects all wavelengths of the visible spectrum equally. White light is a wavelength intensity distribution which creates a hueless sensation to the eye.

X-ray: Nonnuclear EMR of very short wavelength, lying within the interval of 0.1 to 100 A (between gamma rays and ultraviolet radiation). Also called X-radiation, Roentgen rays.

zenith: The point in the celestial sphere that is exactly overhead: opposed to nadir.

These definitions have been reproduced from the Manual of Remote Sensing with the permission of the American Society of Photogrammetry.

Appendix B

COURSE EQUIPMENT LIST

SLIDE SERIES

I.	World Cities	20 Slides	All taken from Skylab
	Environmental Quality	20 Slides	
	General Geology	50 Slides	
	Geomorphic Provinces, Part I	40 Slides	
	Geomorphic Provinces, Part II	40 Slides	
	United States Agriculture	20 Slides	
	World Agriculture	20 Slides	
	Meteorology and Climatology	30 Slides	
	Arid U. S.	35 Slides	
	World Deserts	20 Slides	
	Europe	40 Slides	
	Australia and New Zealand	30 Slides	
	Land Use	30 Slides	
	Glacial Morphology	20 Slides	
	Oceanography	40 Slides	
	Hydrology	50 Slides	
II.	General Interest, Part I	30 Slides	Taken from Gemini, Apollo, and Skylab
	General Interest, Part II	30 Slides	
	General Interest, Part III	35 Slides	
	Geology	55 Slides	
	Geography	55 Slides	
	Oceanography	40 Slides	

Meteorology	50 Slides
Hydrology	20 Slides
SW and Northern Mexico	35 Slides
Full and Partial Earth	10 Slides
Mainland China	30 Slides

III. PLANETOLOGY

Introduction to Lunar Geology	40 Slides
Introduction to Geology of Mars	30 Slides
Martian Dust Storm - Series	20 Slides

IV. EARTH SCIENCES

The United States Regional Series	220 Slides
Alaska: A Regional Overview	20 Slides
Hawaiian Islands: A Regional Overview	20 Slides
Infrared High Altitude Imagery	20 Slides
Volcanism	20 Slides
Glaciology	30 Slides
Arid Land Forms	10 Slides
Fault Features	10 Slides
Inland Land Forms	20 Slides
U.S. Coastlines	30 Slides
Lakes and Reservoirs	25 Slides
River Patterns	20 Slides
Land Use Patterns	20 Slides

	California Coast: An Oblique View	25 Slides
	Northwest California	20 Slides
	The Mad River Watershed of Northern California	60 Slides
	The Mojave River, An Interior Drainage System	35 Slides
	Surface Features of San Andreas Fault	40 Slides
	The Trans-Alaska Pipeline Route	10 Slides
	Urban America	20 Slides
	U.S. Samples	25 Slides
V.	Weather Satellites	20 Slides
	Fullest Resource Analysis	20 Slides
	Application of Remote Sensing and Geologic Hazards	20 Slides
	Sensing Our Earth... The Overview and Prospects	45 Slides
	Hydrology and Dynamics of Land Forms in The Coastal Zone	30 Slides
	The Synoptic View of World Food Resources and Agriculture	30 Slides
	Techniques of Land Use and Management	30 Slides

VI. USGS Topographic Maps

(a) Cape Canaveral, 7.5 minute series, photorevised, 1970
(b) Titusville, 7.5 minute series, photorevised, 1970
(c) Cocoa, 7.5 minute series, photorevised 1970

USGS Map of Florida from LANDSAT

U-2 Photo of Cape Canaveral

Contour Map

Township Map of Rockledge

Colored Pencils

Compass

12" Ruler in British or Metric Units

Hand Magnifying Lens

Glass Jar

Table Lamp

Mirror 3" x 5"

Stock Paper 8 1/2" x 11"

Rough Texture White Paper 8 1/2" x 11"

White Paper 8 1/2" x 11"

Prism

USGS Topographic Map Symbol Sheet #368

Battery Jar

Onion Skin Paper

Glass Plate

Food Coloring

Thermometer

Map of U.S. From ERTS

Planet Earth from Outer Space

Cylinder Tube 12"

Cardboard 3" x 4"

Glue

Scissors

Diffraction Grating

Incandescent Light

Fluorescent Light

Natural Light

Street Light

Advertising Light

Spectroscope

Nichrome Wire

Borax

Cobalt Nitrate

Manganese Dioxide

Copper Sulfate

Ferric Chloride

Chromium Nitrate

Nickel Chloride

Bunson Burner

Protractor

Appendix C

PLACING AN ORDER FOR REMOTELY SENSED DATA AT EROS

Orders for reprodudtions of data from the EROS Data Center are accepted from individuals, governmental organizations, universities, and industries in the United States and foreign countries. Orders can be placed by personal visit, telephone, or mail to the Data Center. Orders can also be placed at any of the EROS Applications Assistance Facilities.

All orders must be accompanied by check, money order, purchase order, or authorized account identification; processing cannot be initiated until valid and accurate payment is received. Your check or money order should be made payable to the U.S. Geological Survey. Standing (open) accounts may be established by repetitive users. To open a standing account, a check must be remitted for the amount to be deposited. You will be informed of the account number, and future orders can be placed using this open account number. You may add to the balance or obtain a refund of the unused portion at any time. A $100 minimum is required to establish a standing account.

Quality of the reproduction cannot exceed that of the master film available at the Data Center. Every product leaving the Data Center undergoes a rigid inspection to insure that internal quality standards are met. Occasionally, you may find that a product has certain defects, such as small scratches, pinholes, or stains, or that the color balance or density of the reproduction is not exactly as you expected it should be. In these cases, you may be assured that it has been inspected against the quality of the original reproducible and that everything has been done to produce as good a product as possible. As with any large production facility, however, substandard products sometimes do reach the user. Such products should be returned to the Data Center for reprocessing or a refund. Our policy is to provide high quality products to all users, and to make certain that data users are satisfied with all products.

All shipments are prepaid, and no postage charges are made. With each outgoing order, a prepaid postage card is included soliciting your comments by return mail. We solicit your suggestions and criticisms as a positive method for improving service and quality.

Should you have difficulty in placing an inquiry or order, need assistance in selection of data, or have questions regarding your order or additional services, you may write or call:

User Services
EROS Data Center
Sioux Falls, South Dakota 57198
Phone: 605-594-6511, extension 151
FTS: 605-784-7511

Please allow a minimum of 2 to 3 weeks for delivery of all orders. A longer time may be required for the production of computer compatible tapes or the completion of very large or complex orders.

Information on the order forms for each type of data is given below:

LANDSAT (EARTH RESOURCES TECHNOLOGY SATELLITE) DATA

LANDSAT data should be ordered with the LANDSAT (ERTS) order form. LANDSAT images are indexed by a unique scene number. If you are ordering from a computer listing, transfer the scene identification number of the selected image from the computer list to the LANDSAT (ERTS) order blank, and complete the order form as indicated on the reverse side. If ordering from other references, please be sure that the scene identification number is included on the order form.

If you are interested only in obtaining a LANDSAT (ERTS) image of an area within the 48 conterminous States of the United States, we suggest that you use the LANDSAT (ERTS) Since Coverage order form. Instructions are on the reverse, and the accompanying map identifies, by a unique number, the nominal center points of each satellite image.

SKYLAB DATA

Skylab photography or imagery should be ordered with the Skylab order form. Each photograph is indexed by scene number; each entry and scene identification number on the computer listing describes a single photograph.

NASA AERIAL PHOTOGRAPHY

NASA aerial photography should be ordered with the NASA Aircraft (Aerial) Photography order form. A careful study should be made of the geographic search computer listing. In most cases, NASA aerial photography is accessed by strip. The number of scenes described by the strip can be determined from the first and last frame numbers and the number of frames on the computer listing. The center coordinates on the computer listing are given for the first frame of the flight line. The four corner geographic coordinates for the entire strip are shown on the second line of the computer listing. In some cases, only one frame is described, in which case interpolation of frames is not required.

When more than one frame is described, it will be necessary to plot the four corner geographic coordinates of the strip on a map. This will show complete coverage of the strip and assist you in the interpolation and selection of the frame(s) covering your area of interest. To do this, the strip must be equally divided into the number of frames identified on the computer listing and those divisions or frames must be assigned a frame number. This will result in a graphic presentation of the strip coverage which will allow you to identify and select the desired frame(s). To insure that you receive the right coverage, it is recommended that you also consider ordering the adjoining frames.

When you have determined which photograph or strip from the computer listing covers your area of interest, an order can be placed by one of the following options:

1. When only one frame is described on the computer listing, transfer the scene identification and frame numbers directly on to the order form.

2. When interpolating an exact frame or frames within a strip, transfer the scene identification number directly and record the first and last frame numbers of the part of the strip you want on the order form.

3. To order the entire series of photos on the strip, transfer the scene identification number and first and last frame numbers directly from the computer listing on to the order form. Refer to the detailed instructions on the reverse side before completing the order form.

AERIAL MAPPING PHOTOGRAPHY

Photo indexes provide access to U.S. Geological Survey and other aerial photography. If you do not have previous knowledge of the photo or frame number, the index must first be ordered so that the appropriate frame number can be found. From the photo index, the project, roll, and frame number can be located and transcribed to the Aerial Mapping Photography order form. Thus, two steps may be required in ordering:

1. Order the photo index for the geographic area of interest, and
2. From the photo index, select and order the individual frames of interest.

Photo indexes can be ordered by using the Aerial Mapping Photography order form or by supplying the geographic location. Indexes also appear on and can be ordered from a computer listing. Individual aerial photographs are not indexed geographically and will not appear on the computer listing. To order a photo index, identify the exact latitude and longitude of the corner coordinates or provide a map with the area outlined. Once you have received the photo index and identified your area of interest put the project, roll, and frame number(s) on to the Aerial Mapping Photography order form.

Aerial photography is usually forward overlapped at least 60 percent and sidelapped at least 30 percent for stereo viewing. (Forward overlap is defined as the area of coverage common to successive photographs along a flight line; sidelap is the area of coverage common to photographs from adjacent flight lines.) Alternate photographs can be ordered within a flight line to provide complete ground coverage. All photo indexes are priced at $3 and are available in 1 or 2 sizes: 10 by 12 inches (25.4 by 30.5 cm) or 20 by 24 inches (51 by 61 cm), depending on the scale and area covered by the photo index. Nine-by nine-inch (23- by 23-cm) paper and film products are automatically dodged when printed. Users desiring undodged products should so state when ordering. (Note: Dodging is a means of controlling the negative's overall exposure to light during the process of printing. By doing this, areas normally dark may be lightened and vice versa to show more detail.) U.S. Geological Survey aerial photography is available only in black and white and has less than 5 percent cloud cover.

PLACING A STANDING ORDER FOR LANDSAT (ERTS) DATA

Two basic options are available for placing standing orders for either data or information from the EROS Data Center:

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1. You may specify an area for which any new LANDSAT imagery will be automatically printed and shipped to you, or
2. You may specify an area for which the Data Center will notify you of any new imagery and the order can subsequently be placed by you.

Should you decide to place a standing order for new data (option 1), you must agree to accept all data for your geographic area if it meets your specifications for cloud cover, quality, and type of remotely sensed data. Any image having any part within the geographic location defined by you will be shipped. You must also establish prepayment with the EROS Data Center by placing money on deposit in a standing account or by issuing a blanket purchase order or valid account number against which you will be billed monthly. If you select option 2, the minimum requirement is that some data be ordered once every 120 days; otherwise the standing order for this information will automatically be cancelled.

CUSTOM PROCESSING

Custom processing to unique scale and image format is also available from the Data Center. These products normally require longer periods of time for completion. Pricing is based on three times the standard price, or for intermediate enlargement, three times that of the next larger size standard product.

When custom processing is required, indicate CUSTOM under REMARKS on the order form and remit triple the standard price.

PRIORITY SERVICES

A priority system for rapid delivery of products is available whereby orders will be shipped within 5 working days of receipt. For providing this service, three times the standard price is charged. Priority processing will only be accepted when imagery is specifically identified and standard products are ordered.

If for any reason shipment is not made within the 5 days, the cost for each product reverts to standard price and a refund or credit is made.

To receive this service, indicate PRIORITY under REMARKS on the order form and remit triple the standard price.

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SPACECRAFT DATA FACT SHEET

ERTS/LANDSAT

On July 23, 1972, the first Earth Resources Technology Satellite (ERTS/LANDSAT-1) was launched into a sun synchronous polar orbit around the Earth. On January 22, 1975, the second Earth Resources Technology Satellite (ERTS/LANDSAT-2) was launched into a similar orbit. Each satellite has the capability for receiving coverage of most of the Earth on an 18-day repetitive cycle. The sensors on board the spacecraft transmit data to NASA receiving stations in Fairbanks, Alaska; Goldstone, California; and Greenbelt, Maryland. The Data received at the NASA receiving stations are forwarded to Goddard Space Flight Center in Greenbelt, Maryland where they are converted to 70mm photographic film positives. Copies of the imagery are immediately flown to the EROS Data Center in Sioux Falls, South Dakota where they are placed in the public domain and where requests for reproductions of the images can be filled for the scientific community and the public at large.

THE ERTS/LANDSAT SENSORS

The ERTS/LANDSAT Spacecraft carry two types of imaging sensors: The Multi-Spectral Scanner Subsystem (MSS) and the Return Beam Vidicon (RBV) cameras.

The Multi-Spectral Scanner (MSS) is a line-scanning device which uses an oscillating mirror to simultaneously scan the terrain passing beneath the spacecraft. The scanner produces four synchronous images, each at a different wave band. The wave length ranges of each band are:

Band 4 (green)	0.5 to 0.6 micrometers
Band 5 (lower red)	0.6 to 0.7 micrometers
Band 6 (upper red-lower infrared)	0.7 to 0.8 micrometers
Band 7 (near infrared)	0.8 to 1.1 micrometers

Band 4 sometimes discriminates, qualitatively, the depth and/or turbidity of standing bodies of water. Band 5 is best for showing topographic and cultural features, such as drainage patterns, roads, and cities. Band 6 shows the best tonal contrasts that reflect various land use practices; it also gives maximum land-water contrast. Band 7 is the best for land-water discrimination.

Thus, for general display purposes, a scene is best presented by four photos. If only one photo is desired, however, band 5 will usually be the best selection.

The Return Beam Vidicon cameras are television cameras mounted side by side in the spacecraft and bore-sighted to simultaneously photograph the earth beneath the spacecraft.

Because of functional problems, the RBV sensors on ERTS/LANDSAT-1 were rendered inoperative on approximately August 15, 1972. Therefore, we have received no RBV images since that time. Some RBV images, acquired prior to its malfunction, are in our film holdings. Some RBV images from ERTS/LANDSAT 2 will be available in limited quantity. The wave length ranges of each band are:

Band 1 (green)	.460 to .600 micrometers
Band 2 (red)	.569 to .680 micrometers
Band 3 (near infrared)	.660 to .820 micrometers

The individual frames of MSS and RBV images cover approximately 115 x 115 miles and overlap by 10 percent along the spacecraft track. They are converted from electronic signals to black and white photographic positives on 70mm film by an Electron Beam Recorder (EBR). These original images have a scale of approximately 1:3,369,000. Master reproducible copies are all System Corrected Images, processed by Goddard Space Flight Center and forwarded to the EROS Data Center as 70mm photographic film negatives.

COLOR COMPOSITES

Only selected scenes of the RBV and MSS images are reproduced as color composites. Therefore, color composites do not exist for all ERTS/LANDSAT scenes. Scenes reproduced as color composites are selected and compiled by NASA and the EROS Data Center as a result of customer requests. Three black and white spectral bands from either the RBV or MSS images are registered and sequentially exposed through appropriate color filters onto color film at a scale of 1:1,000,000.

Inquiry should be made as to the availability of a color composite over a specific area before submitting payment.

ERTS/LANDSAT (continued)

COMPUTER COMPATIBLE TAPES

Computer compatible digital tapes of ERTS/LANDSAT images may be ordered from the Data Center. However, all scenes requested must be prepared in computer compatible tape (CCT) form by NASA/Goddard and forwarded to the EROS Data Center for reproduction.

MICROFILM

After every 30 days, the Goddard Space Flight Center prepares a complete listing of photography and a 16mm "browse" microfilm of images processed. The microfilm are not intended for analysis purposes, but are instead intended to provide visual index to the coverage and a capability for cloud cover assessment by the user. The band 2 RBV and band 5 MSS image from each scene will appear on the microfilm. The microfilm are available for purchase from the Data Center on open reels.

NASA ERTS/LANDSAT DATA CATALOGS

The listing of the imagery shown on the microfilm previously mentioned is published in NASA ERTS/LANDSAT Standard Catalogs. Photographs are not included in the catalogs. Information contained in the catalogs is not always compatible with revisions made of film holdings. It is suggested that inquiry be made to the Data Center for ordering information.

SKYLAB

The NASA Skylab Program consisted of one unmanned and three manned missions. Limited Skylab photos from the three manned missions were acquired from May 22, 1973 through February 8, 1974.

The spacecraft traveled in an equatorial orbit 270 miles above the Earth, and acquired limited data between latitudes 50° north and 50° south. The data cover a number of scattered test sites selected to support Earth Resources Experiments, but do not provide complete and cloud free coverage of these areas.

The Skylab Earth Resources Experiment Package (EREP) used two basic photographic remote sensing systems and was designed as a spaceborne facility to be used by the scientific community. The two basic systems used were:

S190A – Multispectral Photographic Camera – A six camera array designed for a wide range of user oriented subjects. Each camera used 70mm film and a six inch focal length lens. The films utilized ranged in the spectrum from narrow band black and white to broad band color and color infrared.

S190B – Earth Terrain Camera -- A single, high resolution, Earth Terrain Camera selected to support the S190A system. It utilized five inch film and an 18 inch focal length lens. Various films were periodically used in the camera and basically consisted of black and white, color and color infrared.

Skylab imagery is indexed and listed at the Data Center by individual scene. Each Skylab image, viewed from an altitude of approximately 270 miles, covers the following general areas depending on the camera system: the S190A system covers approximately 100 miles by 100 miles. The resolution of S190A photos is such that an object of about 150 feet by 150 feet can be identified. The S190B system covers approximately 68 miles by 68 miles. The resolution of S190B photos is such that an object of about 75 feet by 75 feet can be identified. The resolution of any scene depends on the contrast of the cultural and geological features as well as the atmospheric conditions.

The Skylab flights have been completed and all photographic data from missions 2, 3, and 4 are available from the Data Center.

APOLLO/GEMINI PHOTOGRAPHY

Early photographic coverage over limited geographic areas of the Earth acquired by the Gemini and Apollo missions is available from the Data Center. The majority of this coverage is color photography, acquired by handheld 70mm cameras.

AIRCRAFT DATA FACT SHEET

AERIAL MAPPING PHOTOGRAPHY

Aerial Mapping Photography acquired by the United States Geological Survey is used primarily for topographic mapping of the continental United States. Reproductions from this imagery are available in black and white only. The photography is cloud free and roads and buildings are easily discernible.

Based on the initial purpose of the photography, the altitude from which they were acquired varies considerably, but usually ranges from 12,000 feet to 25,000 feet. The basic format of individual photographs is 9 inches by 9 inches and they cover from 3 to 7 miles on a side, depending on the scale of the photography.

Due to the large number of photographs available from Aerial Mapping Photography, the photographs have been combined into block coverage, or photo indexes. A photo index is a series of overlapping aerial photographs combined to form a composite aerial view of a specific area. The majority of the photo indexes are 7½ minute quadrangles which cover approximately 8 miles by 10 miles.

Presently, over 50,000 photo indexes are available at the Data Center. To order Aerial Mapping Photography will require that you obtain a photo index over your area of interest. This will allow you to view the existing coverage and to order individual photographs from the photo index that satisfy your requirements.

NASA AIRCRAFT PHOTOGRAPHY

NASA Aircraft imagery is the result of the NASA Earth Resources Aircraft Program. This program is directed primarily at testing a variety of remote sensing instruments and techniques, generally over certain preselected test sites within the continental United States.

The research aircraft are operated and scheduled by NASA field centers. Aircraft coverage resulting from U-2 and RB-57 flights are available in varied scales. High altitude coverage varied between 60,000 feet and 65,000 feet. Limited low altitude coverage is also available.

Various cameras and films were used and the resulting products are available in black and white, color, and /or color infrared. Since high resolution camera equipment is employed, ground features such as roads, farms, and cities are easily identifiable. It should be understood that due to the location of the preselected test sites, photographic coverage may not be available over your area of interest.

INQUIRY FORM
GEOGRAPHIC COMPUTER SEARCH

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DATE ____________

NAME MR / MS ____________ (FIRST) ____________ (INITIAL) ____________ (LAST)

ACCOUNT NO ____________ (IF KNOWN)

COMPANY ____________ (IF BUSINESS ASSOCIATED)

PHONE (Bus.) ____________

ADDRESS ____________

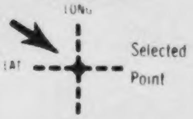
PHONE (Home) ____________

CITY ____________

Your Ref. No ____________ (P.O. GOVT ACCT OR OTHER)

TO INITIATE AN INQUIRY AND COMPUTER GEOSEARCH COMPLETE THE FOLLOWING

POINT SEARCH



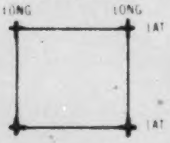
Imagery with any coverage over the selected point will be included

	POINT #1	POINT #2	POINT #3
Latitude	____ ° ____ ' N or S	____ ° ____ ' N or S	____ ° ____ ' N or S
Longitude	____ ° ____ ' E or W	____ ° ____ ' E or W	____ ° ____ ' E or W

Landsat Only (Worldwide Reference System)

Path ____	Path ____	Path ____	Path ____	Path ____
Row ____	Row ____	Row ____	Row ____	Row ____

AREA RECTANGLE



Imagery with any coverage over the selected area will be included

	AREA #1	AREA #2	AREA #3
Lat	____ ° ____ ' N or S to	____ ° ____ ' N or S to	____ ° ____ ' N or S to
Lat	____ ° ____ ' N or S	____ ° ____ ' N or S	____ ° ____ ' N or S
Long	____ ° ____ ' E or W to	____ ° ____ ' E or W to	____ ° ____ ' E or W to
Long	____ ° ____ ' E or W	____ ° ____ ' E or W	____ ° ____ ' E or W

If the above geographic coordinates cannot be supplied, please specify area by GEOGRAPHIC NAME AND LOCATION (include a map if possible.)

PREFERRED TYPE OF COVERAGE

	Black & White	Color or Color Infrared
☐ Landsat	☐	☐
☐ Skylab	☐	☐
☐ Nasa Aircraft	☐	☐
☐ Aerial Mapping Photography (Minimum color available)		

PREFERRED TIME OF YEAR
Check maximum of three

- ☐ JAN-MAR
- ☐ APR-JUNE
- ☐ JULY-SEPT
- ☐ OCT-DEC
- ☐ All coverage
- ☐ Latest coverage
- ☐ SPECIFIC DATES ____________

NOTE: Seasonal coverage normally applies only to Landsat coverage.

MINIMUM QUALITY RATING ACCEPTABLE

☐ 0-2 (VERY POOR) ☐ 3-4 (POOR) ☐ 5-6 (FAIR) ☐ 7-9 (GOOD)

MAXIMUM CLOUD COVER ACCEPTABLE

☐ 10% ☐ 30% ☐ 50% ☐ 80% ☐ 100%

NOTE: Classification of percent of cloud cover is subjective and is relative to the amount of clouds appearing on the imagery and not to their location.

APPLICATION AND INTENDED USE ____________

FORM 9-1936
(Jan. 1977)

Return completed form to the facility nearest you.

NCIC HEADQUARTERS
U.S. Geological Survey
507 National Center
Reston, VA 22092
FTS: 928-6045
COMM: 703-860-6045

EROS APPLICATIONS FACILITY
NSTL
U.S. Geological Survey
Bay St. Louis, MS 39520
FTS: 494-3541
COMM: 688-3472

NCIC MID-CONTINENT
U.S. Geological Survey
1400 Independence Rd.
Rolla, MO 65401
FTS: 276-9107
COMM: 314-364-3680

EROS DATA CENTER
U.S. Geological Survey
Sioux Falls, SD 57198
FTS: 784-7151
COMM: 605-594-6511

NCIC ROCKY MOUNTAIN
U.S. Geological Survey
Stop 510, Box 25046
Denver Federal Ctr.
Denver, CO 80225
FTS: 234-2326
COMM: 303-234-2326

NCIC WESTERN
U.S. Geological Survey
345 Middlefield Rd.
Menlo Park, CA 94025
FTS: 467-2427
COMM: 415-323-8111

HOW TO REQUEST A GEOGRAPHIC SEARCH

This form is used to request a computer search for imagery over a point or area of interest.

Data from this inquiry sheet will be used to initiate a computer Geosearch. The results will be returned on a computer listing along with a decoding sheet, from which imagery can be selected and ordered.

Complete the form as follows:

A. Enter your NAME, ADDRESS, and ZIP CODE clearly. If you have had previous contact with that facility, include your ACCOUNT number. Enter a PHONE number where you can be reached during business hours.

B. Complete the required information for either the POINT SEARCH, or AREA RECTANGLE inquiry, which includes the geographic LATITUDE and LONGITUDE coordinates. If coordinates are not available, please supply the GEOGRAPHIC NAME AND LOCATION or a map with the area of interest identified. It is beneficial that you minimize your area of interest, thereby allowing for a faster and more critical retrieval of information.

C. Complete all other information.

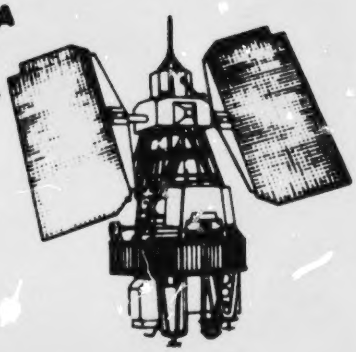
D. Complete the APPLICATION AND INTENDED USE portion of the inquiry. e.g. Will it be used for identifying buildings or will it be framed and placed on a wall. This information will assist our technicians in determining whether the products available will satisfy your requirements.

E. Return completed form to the FACILITY NEAREST YOU.

NOTE: If an inquiry is made for Landsat Data, and the Worldwide Reference of PATH and ROW numbers are available, please insert them in the appropriate locations. Otherwise, geographic coordinates will suffice.

SATELLITE IMAGE MOSAIC

SPACEVIEW OF FLORIDA



A mosaic of satellite images showing Florida from about 570 miles in space has been prepared by the U.S. Geological Survey and is for sale at $3.00 per copy. The "false-color" mosaic was made from parts of 18 separate images recorded by a multispectral line scanner on NASA's LANDSAT-1 (formerly ERTS-1) between November 1972 and April 1974. The colors of the mosaic are not natural because they combine visible and infrared bands of the spectrum. For instance, green vegetation appears red, urban areas are bluish-gray, bare ground and sand are light colors, and water ranges from black to light blue, depending on its sediment load and depth. Outlines of such features as Lake Okeechobee, the Everglades, Tampa Bay, the Florida Keys, and urban development in Miami, Tampa, Orlando, Jacksonville and other metropolitan areas are clearly displayed.

The Florida mosaic is 44 x 58 inches and is at a scale of 1:500,000, that is, 1 inch equals about 8 miles.

MAIL ORDER FORM To:
U.S. Geological Survey, Branch of Distribution, 1200 South Eads Street,
Arlington, VA 22202.

Enclosed find $_________ (check or money order made payable to U.S. Geological Survey). Please send me _________ copies of FLORIDA SATELLITE IMAGE MOSAIC at $3.00 per copy.

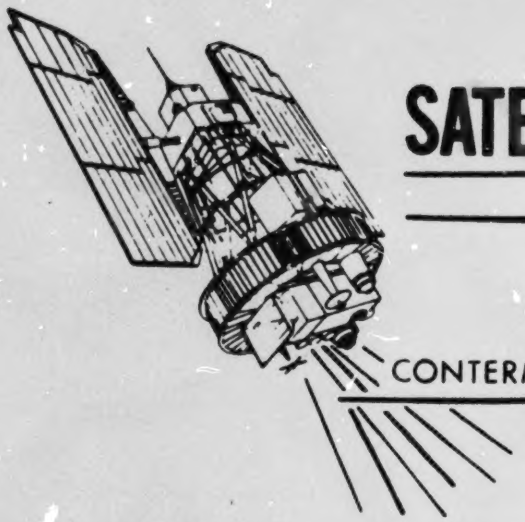
Please print or type your address on label below

Name ____

Street Address _____________________________________

City and State ________________________ Zip Code _________

Information on the availability of individual satellite images used in compiling this mosaic, and other satellite images, may be obtained from the EROS Data Center, Sioux Falls, SD 57198.



SATELLITE IMAGE MOSAIC

CONTERMINOUS UNITED STATES

AN IMAGE MOSAIC OF THE CONTERMINOUS UNITED STATES - the first ever assembled from space imagery - forms an objective record of this Nation as it is today -- on the eve of its 200th birthday. The value of the mosaic is in forming a base for current analyses of resource features and a basis for future comparisons of the environment today with that of tomorrow.

The mosaic was prepared by the Soil Conservation Service by putting together 595 individual cloud-free black and white images taken by NASA's LANDSAT (formerly ERTS-1) during the period July 25 to October 31, 1972.

Each image covers an area 115 x 115 miles and was taken at an altitude of about 570 miles (915 kilometres).

LANDSAT-1 passes over the same spot on the Earth every 18 days and is sending back images in four wavelength bands of the spectrum. Each one of these bands has special information attributes for resources applications.

The mosaic has been compiled in two different bands. Band 5 consists of images scanned to reproduce the red portion of the visible spectrum. This wavelength results in imagery most nearly like normal black and white pictures of cultural features. Band 7 imagery is scanned in the nonvisible near-infrared portion of the spectrum. This imagery is best for showing lakes, streams, marshes, and other bodies of water which appear very much darker than any dry land features and vegetation that appears in light tones in the reproduction.

The mosaic is available for sale to the public in two types of reproduction, photographic and lithographic.

Reproductions printed on stable-base photographic paper may be purchased at varying scales, sizes and prices (for example, 1:5,000,000 scale - $20.00) from the Soil Conservation Service, Federal Building, Hyattsville, MD 2078[illegible].

A one sheet mosaic is available as a lithograph in either band 5 or band 7 from the U. S. Geological Survey.

- *SCALE - 1:5,000,000, that is, 1 inch equals 79 miles (127 kilimetres).*
- *SIZE - 40 x 30 inches (approximately 1.0 x 0.76 metres).*

MAIL ORDER FORM TO:

U. S. Geological Survey, Branch of Distribution, 1200 South Eads Street, Arlington, VA 22202

Enclosed find $________ (check or money order made payable to U. S. Geological Survey) for ERTS-1 Mosaic of the U. S.

Please send: ________ Lithograph(s), Band 5 ☐ $1.25 per copy ________ Lithograph(s), Band 7 ☐ $1.25 per copy

Please print or type your address on label below:

Name ____

Street Address ____

City and State ______________________________ *Zip* __________

Information on the availability of individual satellite images used in compiling this mosaic, and other satellite images, may be obtained from the EROS Data Center, Sioux Falls, SD 57198.

PRICE LIST

STANDARD REMOTE SENSING DATA

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

JANUARY 1, 1977

SATELLITE DATA

STANDARD LANDSAT

IMAGE SIZE	NOMINAL SCALE	PRODUCT FORMAT	BLACK and WHITE UNIT PRICE	BLACK and WHITE PRODUCT CODE	COLOR UNIT PRICE	COLOR PRODUCT CODE
56.8mm (2.2 in.)	1:3369000	Film Positive	$8.00	11		
55.8mm (2.2 in.)	1:3369000	Film Negative	10.00	01		
18.5cm (7.3 in.)	1:1000000	Paper	8.00	23	$12.00	63
18.5cm (7.3 in.)	1:1000000	Film Positive	10.00	13	15.00	53
18.5cm (7.3 in.)	1:1000000	Film Negative	10.00	03		
37.1cm (14.6 in.)	1:500000	Paper	12.00	24	25.00	64
74.2cm (29.2 in.)	1:250000	Paper	20.00	26	50.00	66
COLOR COMPOSITE GENERATION					50.00	59

NOTE: 1) Portrayed in false color (infrared) and not true color
2) Cost of product from this composite must be added to total cost

COMPUTER COMPATIBLE TAPES (CCT)

TRACKS	b.p.i.	FORMAT	SET PRICE	PRODUCT CODE
7	800	Tape Set	$200.00	82
9	800	Tape Set	200.00	83
9	1600	Tape Set	200.00	84

MANNED SPACECRAFT DATA

SKYLAB S190A

IMAGE SIZE	NOMINAL SCALE	PRODUCT FORMAT	BLACK and WHITE UNIT PRICE	BLACK and WHITE PRODUCT CODE	COLOR UNIT PRICE	COLOR PRODUCT CODE
55.8mm (2.2 in.)	1:2850000	Film Positive	$ 8.00	11	$10.00	51
56.8mm (2.2 in.)	1:2850000	Film Negative	10.00	01		
16.3cm (6.4 in.)	1:1000000	Paper	8.00	23	12.00	63
[illegible]2.5cm ([illegible]2.8 in.)	1:500000	Paper	12.00	24	25.00	64
65.0cm (25.6 in.)	1:250000	Paper	20.00	26	50.00	66

SKYLAB S190B

IMAGE SIZE	NOMINAL SCALE	PRODUCT FORMAT	BLACK and WHITE UNIT PRICE	BLACK and WHITE PRODUCT CODE	COLOR UNIT PRICE	COLOR PRODUCT CODE
11.4cm (4.5 in.)	1:950000	Paper	$ 6.00	22	$ 8.00	62
11.4cm (4.5 in.)	1:950000	Film Positive	8.00	12	12.00	52
11.4cm (4.5 in.)	1:950000	Film Negative	10.00	02		
21.8cm (8.6 in.)	1:500000	Paper	8.00	23	12.00	63
43.4cm (17.1 in.)	1:250000	Paper	12.00	24	25.00	64
86.9cm (34.2 in.)	1:25000	Paper	20.00	26	50.00	66

APOLLO/GEMINI

IMAGE SIZE	NOMINAL SCALE	PRODUCT FORMAT	BLACK and WHITE UNIT PRICE	BLACK and WHITE PRODUCT CODE	COLOR UNIT PRICE	COLOR PRODUCT CODE
56.8mm (2.2 in.)	Variable	Film Positive	$ 8.00	11	$10.00	51
56.8mm (2.2 in.)	Variable	Film Negative	10.00	01		
22.6cm (8.9 in.)	Variable	Paper	8.00	23	12.00	63
45.5cm (17.9 in.)	Variable	Paper	12.00	24	25.00	64

AIRCRAFT DATA

AERIAL MAPPING

IMAGE SIZE	PRODUCT FORMAT	BLACK and WHITE		COLOR	
		UNIT PRICE	PRODUCT CODE	UNIT PRICE	PRODUCT CODE
22.9cm (9.0 in.)	Paper	$ 3.00	23	$ 7.00	63
22.9cm (9.0 in.)	Film Positive	5.00	13	15.00	53
22.9cm (9.0 in.)	Film Negative	6.00	03		
45.7cm (18.0 in.)	Paper	10.00	24	25.00	64
68.6cm (27.0 in.)	Paper	15.00	25	30.00	65
91.4cm (36.0 in.)	Paper	20.00	26	50.00	66

PHOTO INDEXES

IMAGE SIZE	PRODUCT FORMAT	BLACK and WHITE		FILM SOURCE
		UNIT PRICE	PRODUCT CODE	
25.4x30.5cm (10x12 in.)	Paper	$ 5.00	36	B & W – Size A
OTHER	Paper	5.00	37	B & W – Size B

NASA RESEARCH

IMAGE SIZE	PRODUCT FORMAT	BLACK and WHITE		COLOR	
		UNIT PRICE	PRODUCT CODE	UNIT PRICE	PRODUCT CODE
55.8mm (2.2 in.)	Film Positive	$ 3.00	11	$10.00	51
55.8mm (2.2 in.)	Film Negative	4.00	01		
11.4cm (4.5 in.)	Paper	3.00	22	7.00	62
11.4cm (4.5 in.)	Film Positive	4.00	12	12.00	52
11.4cm (4.5 in.)	Film Negative	5.00	02		
22.9cm (9.0 in.)	Paper	3.00	23	7.00	63
22.9cm (9.0 in.)	Film Positive	5.00	13	15.00	53
22.9cm (9.0 in.)	Film Negative	6.00	03		
22.9x45.7cm (9x18 in.)	Paper	6.00	31	20.00	69
22.9x45.7cm (9x18 in.)	Film Positive	10.00	14	30.00	56
22.9x45.7cm (9x18 in.)	Film Negative	12.00	04		
45.7cm (18.0 in.)	Paper	10.00	24	25.00	64
68.6cm (27.0 in.)	Paper	15.00	25	30.00	65
91.4cm (36.0 in.)	Paper	20.00	26	50.00	66

MISCELLANEOUS

MICROFILM

FORMAT	BLACK and WHITE		COLOR	
	ROLL PRICE	PRODUCT CODE	ROLL PRICE	PRODUCT CODE
16mm (30.5m/100 ft.)	$15.00	72	$40.00	73
35mm (30.5m/100 ft.)	20.00	72	45.00	73

KELSH PLATES

FORMAT	BLACK and WHITE	
	UNIT PRICE	PRODUCT CODE
Contact Prints on Glass Specify thickness (0.25 or 0.06 inch) and method of printing (emulsion to emulsion or through film base).	$12.00	70

TRANSFORMED PRINTS

FORMAT	BLACK and WHITE	
	UNIT PRICE	PRODUCT CODE
From convergent or transverse low oblique photographs	$ 8.00	71

VIEWING SLIDES

FORMAT	COLOR	
	UNIT PRICE	PRODUCT CODE
35mm mounted duplicate of available printing master	$ 1.00	60

NOTE: 35mm original will require additional $5.00, not to include cost of mounted duplicate.

Complete roll reproduction delivered in roll format carries a 50% reduction in frame pricing.

Custom processing of non-standard products is available at three times the standard product price. If a non-standard size is desired, the cost is three times the next larger standard product price.

Priority service with guaranteed five working days shipment is offered for standard products only, at three times the standard product price.

Extra care should be taken to insure that monies and related order forms are forwarded to the same facility.

☆ U.S. G.P.O. 1977-766-398/61 REG.#6

APPENDIX D

STUDENT LABORATORY

STANDARD OUTLINE FORM

Materials

Quantity	Item

Purpose

A brief statement discussing the purpose of this laboratory activity as related to stated teacher objectives.

Procedure

A detailed step-by-step description of your activities with rationale as to why each step was taken in that order.

Results Obtained

A detailed summary of the results of your activities as related to the previously stated purpose.

Conclusion

A detailed discussion of your findings as related to the unit of study.

APPENDIX E

LOCAL POSSIBLE PROJECT STUDIES

1. Vegetation in the St. John's River
2. Turbidity Plumes from Sewage Outfalls
3. Transportation Corridors in Brevard County
4. Mapping of Orange Groves
5. Mosquito Control Dike Mapping
6. Urban Development
7. Hydrology Sources
8. Agriculture Mapping
9. Marshland
10. Federal versus Private Land Mapping
11. Selected Fauna Habitats
12. Selected Flora Habitats
13. Ocean Depth Mapping
14. Intercoastal Waterway Mapping
15. Land Use Planning
16. Range Resources
17. Forestry Planning
18. Geology Mapping
19. Sand Drift Mapping
20. Canal Mapping

APPENDIX F

TABLE OF METRIC MEASURE

METRIC UNITS

Linear Measure (length)

10 millimeters (mm) = 1 centimeter (cm)
10 centimeters = 1 decimeter (dm)
10 decimeters = 1 meter (m)
10 meters = 1 dekameter (dam)
10 dekameters = 1 hectometer (hm)
10 hectometers = 1 kilometer (km)

Square Measure (area)

$100\ mm^2 = 1\ cm^2$
$10{,}000\ cm^2 = 1\ m^2$
$10{,}000\ m^2 = 1$ hectare
$1{,}000{,}000\ m^2 = 1\ km^2$

Cubic Measure (volume)

$1000\ mm^3 = 1\ cm^3$
$1{,}000{,}000\ cm^3 = 1\ m^3$
$1{,}000{,}000{,}000\ m^3 = 1\ km^3$

Mass/Weight

10 mg = 1 cg
100 cg = 1 gram (g)
1000 g = 1 kilogram (kg)
1000 kg = 1 metric ton (tonne)

Capacity

10 ml = 1 cl
100 cl = 1 liter (l)
1000 l = 1 kl

APPROX. EQUIVALENTS

Linear Measure (length)

1 mm = 0.04 in
1 cm = 0.39 in
1 m = 39.37 in
1 km = 0.62 mi
2.54 cm = 1 in
0.91 m = 1 yd.

Square Measure (area)

$1\ cm^2 = 0.16\ in^2$ | $6.45\ cm^2 = 1\ in^2$
$1\ m^2 = 10.76\ ft^2$ | $0.09\ m^2 = 1\ ft^2$
$1\ km^2 = 0.38\ mi^2$ | $0.84\ m^2 = 1\ yd^2$
1 hectare = 2.47 acres

Cubic Measure (volume)

$1\ cm^3 = 0.06\ in^3$ | $1\ m^3 = 35.31\ ft^3$
$16.39\ cm^3 = 1\ in^3$
$0.028\ m^3 = 1\ ft^3$

Mass/Weight

1 g = 0.04 oz | 1 kg = 2.20 lb
28.35 g = 1 oz
0.45 kg = 1 lb
907.18 kg = 1 ton (2000 lb)

Capacity

1 l = 2.11 pt | 1 l = 1.06 qt.
1 l = 0.26 gal
3.79 l = 1 gal

APPROX. CONVERSION TO METRIC MEASURES

When you know	Multiply by	To find
inches	2.54	centimeters
feet	30.48	centimeters
yards	0.91	meters
miles	1.61	kilometers
sq. inches	6.45	sq. centimeters
sq. feet	0.09	sq. meters
sq. yards	0.84	sq. meters
sq. miles	2.59	sq. kilometers
acres	0.40	hectares

When you know	Multiply by	To find
ounces	28.35	grams
pounds	0.45	kilograms
short tons (2000 lbs.)	0.91	tonnes
teaspoons	4.93	milliliters
tablespoons	14.79	milliliters
fluid ounces	29.57	milliliters
cups	0.24	liters
pints	0.47	liters
quarts	0.95	liters
gallons	3.79	liters

METRIC PLACE VALUE

Place Value (multiples of 10)	1000	100	10	1	1/10	1/100	1/1000
Exponents	10^3	10^2	10^1	10^0	10^{-1}	10^{-2}	10^{-3}
Money (U.S.)	\$1,000.00	\$100.00	\$10.00	\$1.00	\$.10 dime	\$.01 cent	\$.001 mill
Linear Measure	kilometer (km)	hectometer (hm)	dekameter (dam)	meter (m)	decimeter (dm)	centimeter (cm)	millimeter (mm)
Capacity	kiloliter (kl)	hectoliter (hl)	dekaliter (dal)	liter (l) (1 dm^3)	deciliter (dl)	centiliter (cl)	milliliter (ml)
Mass/Weight	kilogram (kg)	hectogram (hg)	dekagram (dag)	gram (g)	decigram (dg)	centigram (cg)	milligram (mg)
Place Value (multiples of 100)	1,000,000	10,000	100	1	1/100	1/10,000	1/1,000,000
Square Measure (area)	square kilometer (km^2)	square hectometer (hm^2)	square dekameter (dam^2)	square meter (m^2)	square decimeter (dm^2)	square centimeter (cm^2)	square millimeter (mm^2)
Place Value (multiples of 1000)	1,000,000,000	1,000,000	1000	1	1/1000	1/1,000,000	1/1,000,000,000
Cubic Measure (volume)	cubic kilometer (km^3)	cubic hectometer (hm^3)	cubic dekameter (dam^3)	cubic meter (m^3)	cubic decimeter (dm^3)	cubic centimeter (cm^3)	cubic millimeter (mm^3)

APPENDIX G

COLLEGE AND UNIVERSITY SOURCES OF REMOTE SENSING INFORMATION

A listing of colleges by types of publications generated and by application-oriented disciplines pursued.

Principal Investigator
TIMOTHY C. BIDWELL
Technicolor Graphic Services, Inc.

Photogrammetric Engineering and Remote Sensing
Vol. 41, No. 10, October 1975

ABSTRACT

Research in remote-sensing applications has increased dramatically since the launch of the Earth Resources Technology Satellite-1 (ERTS-1, renamed LANDSAT-1) and Skylab's Earth Resources Experiment Package (EREP). It is becoming increasingly more difficult to keep abreast of university research publications related to remote sensing. To assist researchers in locating those universities that are actively publishing research material in remote-sensing technology and applications, this paper lists major colleges by types of publications generated and by application-oriented disciplines pursued, and includes a geographical index.

INTRODUCTION

The publication and availability of information on all aspects of remote-sensing applications have increased a great deal in the past few years. The Earth Resources Technology Satellite (ERTS, renamed LANDSAT) and Skylab's Earth Resources Experiment Package (EREP) have provided images of most of the land surfaces of the world for analysis. The availability and distribution of these data from the U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota, have expanded the analysis of remotely sensed data from a few select scientists to hundreds of interested researchers in government, industry, and universities. Thousands of research reports already have been published on techniques of analysis and applications of remote-sensing data. The continuation of the LANDSAT series of satellites, with the launch of LANDSAT 2 in January, 1975, and the expansion of research and interest in remote-sensing applications in all scientific disciplines will further add to the volume of published information.

Maintaining an up-to-date knowledge of information that has been published, even for application in one discipline, has become increasingly difficult. There is a need to assist people everywhere in locating information relevant to their particular needs. This paper is intended to serve as a listing of the major colleges and universities that are active in remote-sensing related research, and that either publish material themselves or have staffs that author materials published elsewhere.

The list is based upon a questionnaire which was sent in the fall of 1974 to more than 200 college departments that have in the past taught courses or published information in remote sensing.[1] A total of 78 departments reported positively out of the 125 respondents.

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[1] The author would like to thank Dr. Robert Baker of Stephen F. Austin University for his assistance in compilation of the original mailing list, although any omissions are solely the author's responsibility.

It is anticipated that some departments may have begun publishing since this survey or were missed in the original survey. These departments should be brought to the author's attention for inclusion in a future listing.

NEWSLETTERS

University of Arizona Remote Sensing Newsletter
Published irregularly. Reports on Arizona projects and other information of interest to local researchers.

Contact: University of Arizona
Office of Arid Land Studies
1201 East Speedway Blvd.
Tucson, Arizona 85719
(602) 884-1955

The Cornell Remote Sensing Newsletter
Published monthly. Short articles of interest in all aspects of remote sensing.

Contact: College of Engineering
Remote Sensing Program
464 Hollister Hall
Cornell University
Ithaca, New York 14850
(607) 256-4330

Environmental Remote Sensing Applications Laboratory (ERSAL) Newsletter
Published irregularly. Reports news on land use planning projects within Oregon.

Contact: Environmental Remote Sensing
Applications Laboratory
Oregon State University
Corvallis, Oregon 97331
(503) 754-3056

Kansas Environmental Resource Studies (KERS) Newsletter
Published monthly. Publishes articles of interest to scientists in the Midwest.

Contact: The University of Kansas
Center for Research
KERS Newsletter
2385 Irving Hill Road-
Campus West
Lawrence, Kansas 66015
(913) 864-3441

Nebraska Remote Sensing News
Published irregularly. Articles emphasize land use applications in Nebraska.

Contact: Remote Sensing Center
University of Nebraska
Conservation and Survey Division
113 Nebraska Hall
Lincoln, Nebraska 68508
(402) 472-3471

Remote Sensing Institute Newsletter
Published irregularly. Reports the activities of the Institute.

Contact: Remote Sensing Institute
South Dakota State University
Brookings, South Dakota 57006
(605) 688-4184

Remote Sensing of the Electromagnetic Spectrum (RSEMS)
Published January, April, July, and October, for the Association of American Geographers Committee on Remote Sensing. This is "a forum devoted to the communication and exchange of ideas in remote sensing. . . ." Price $1.00.

Contact: Department of Geography
Michigan State University
East Lansing, Michigan 48823
(517) 355-4647

REMOTE SENSING INSTITUTES, LABORATORIES, AND PROGRAMS

This section lists 15 universities or colleges having a designated section devoted to remote sensing research. These institutions have a multidisciplinary staff available, more elaborate facilities than individual departments, and a formalized method of distribution for their materials.

503

University of California - Berkeley
Remote Sensing Research Program
School of Forestry and Conservation
Berkeley, California 94720
Subjects: Forestry, agriculture, range management, water resources.
Publications: Research papers, books, MS and PhD theses.[2]
Distribution: NTIS[3] and by request.

University of Idaho
Geology Department
Geophotography and Remote Sensing Center
Moscow, Idaho 83843
Subjects: Geology, hydrology.
Publications: Research papers, maps (without text), MS and PhD theses, bibliography of publications.
Distribution: By request from Idaho Bureau of Mines and Geology, and University of Idaho (nominal fee).

University of Kansas Center for Research
Remote Sensing Laboratory
2291 Irving Hill Drive-Campus West
Lawrence, Kansas 66045
Subjects: Land use, agriculture, soil moisture, microwave, analog, and digital optical systems.
Publications: Research papers, MS and PhD theses, newsletter, bibliography of publications.
Distribution: By request for specific title.

University of Miami
Department of Mechanical and Industrial Engineering
Remote Sensing Laboratory
P.O. Box 248003
Coral Gables, Florida 33124
Subjects: Meteorology, oceanography, air and water pollution (including thermal pollution), water resources.
Publications: Research papers, MS and PhD theses, listing of previous publications.
Distribution: Special distribution lists, Defense Documentation Center.[4]

University of Michigan
Remote Sensing Program
Ann Arbor, Michigan 48104
Subjects: Forestry, wildlife, insect/plant disease detection, land use, light reflection, energy flow modeling, geological prospecting, water quality, urban analysis.
Publications: Research papers, MS (remote sensing) and PhD theses.
Distribution: NTIS, by request for specific title.

University of Minnesota
Remote Sensing Laboratory
College of Forestry
St. Paul, Minnesota 55108
Subjects: Forestry, range, hydrology.
Publications: Research papers, research progress notes, MS and PhD theses, bibliography of publications.
Distribution: By request.

University of New Mexico
Technology Applications Center
Albuquerque, New Mexico 87131
Subject: Multidisciplinary.
Publications: Quarterly literature review of the remote sensing of natural resources ($50 per year), specific computer bibliographies as requested, educational slide series, research papers.
Distribution: By request for products (cost varies).

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[2] These can be obtained from University Microfilms, 300 North Zeeb Road, Ann Arbor, Michigan, 48106, or from the author's university library.

[3] The National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia, 22161.

Oregon State University
Environmental Remote Sensing
Applications Laboratory
Corvallis, Oregon 97331
Subject: Applications to problem solving in resource management.
Publications: NASA Annual Reports, MS and PhD theses, newsletter.
Distribution: Mailing list.

Pennsylvania State University
Office for Remote Sensing of Earth Resources
Space Science and Engineering Laboratory
219 Electrical Engineering West
University Park, Pennsylvania 16802
Subject: Multidisciplinary.
Publications: Research papers, research progress notes, list of technical reports.
Distribution: NTIS and by request for specific title of technical reports.

Purdue University
LARS
1220 Potter Drive
West Lafayette, Indiana 47907
Subject: Computer-aided analysis techniques in most disciplines.
Publications: Research papers, books, information note series, short course notes, TV tapes, and other audio-visual materials, bibliography of information notes.
Distribution: By request for specific information note.

Stanford University
Department of Applied Earth Science
Remote Sensing Laboratory
Stanford, California 94305
Subject: Geology, soil types, computer techniques, geobotany.
Publications: Research papers, technical report series, bibliography listed in front of technical reports.
Distribution: **Mailing list.**

University of Tennessee Space Institute
Remote Sensing of Earth Resources and Environment
Tullahoma, Tennessee 37388
Subject: No specific area designated.
Publications: Research papers, books, MS and PhD theses, bibliography of publications.
Distribution: By announcement.

Texas A & M University
Remote Sensing Center
College Station, Texas 77843
Subject: Multidisciplinary.
Publications: Research papers, research progress notes, MS and PhD theses, bibliography of publications.
Distribution: By request for specific title.

University of Washington
Department of Urban Planning
Remote Sensing Applications Laboratory
Mail Stop J0-40
Seattle, Washington 98195
Subject: Land occupancy, environmental mapping and analysis.
Publications: Research papers, research progress notes, MS and PhD theses, bibliography of publications.
Distribution: By request (at reproduction cost where supply is exhausted).

SUBJECT INDEX

This section lists those universities having departments or staffs that publish remote-sensing

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[4] Defense Documentation Center, Cameron Station, Alexandria, Virginia, 22314.

research information. The list is organized into several subject areas; those departments that either did not specify a particular subject or were interested in more than the subject listed are in the category entitled "Multidisciplinary." Each university's address, special subject interests, type of publications, and method of distribution is then listed.

Particular attention should be given to the method of distribution, because the reporting departments differ widely in their ability to respond to requests for publications or information. Nearly half of the colleges listed distribute a bibliography of their publications or maintain a mailing list of researchers to whom they will send information. This type of distribution assists those people wishing to keep up-to-date with a particular university's research, or select specific articles to obtain. The other forms of distribution are less formal and in many cases one needs to know specific titles of papers or authors to contact.

Agriculture

Kansas State University
Agronomy Department
Manhattan, Kansas 66506
Subject: Agriculture.
Publications: Research reports, research progress notes, PhD theses.
Distribution: By request.

Michigan State University
Department of Botany-Plant Pathology
East Lansing, Michigan 48824
Subject: Agriculture, plant disease detection.
Publications: Research papers, research progress notes.
Distribution: By request.

Archeology

Chaco Center (in cooperation with the University of New Mexico)

National Park Service
P.O. Box 26176
Albuquerque, New Mexico 87125
Subject: Archeology/anthropology.
Publications: Research papers, books, informal bibliography.
Distribution: Through publisher or by request.

Computer techniques

Oregon State University
Engineering Experiment Station
Corvallis, Oregon 97331
Subject: Computer techniques.
Publications: Research papers, research progress notes, MS and PhD theses.
Distribution: Mailing list.

Data Processing

Boston University
Geography Department
Boston, Massachusetts 02215
Publications: Research papers, PhD theses.
Distribution: On request from authors.

University of Hawaii
Geography Department
Manoa Campus
Honolulu, Hawaii 96822
Subject: Enchancement techniques, pattern recognition, and optical data processing.
Publications: Research papers, PhD theses.
Distribution: Mailing Lists of University of Hawaii Water Resources Research Center.

Engineering

Clemson University
Civil Engineering
Clemson, South Carolina 29631
Subject: Engineering.
Publications: Research papers, MS theses.
Distribution: By request.

Colorado State University
Department of Civil Engineering
Ft. Collins, Colorado 80521
Subject: River mechanics.
Publications: Research papers, MS theses.
Distribution: NTIS and by request for specific title.

Georgia Institute of Technology
Civil Engineering Department
Atlanta, Georgia 30332
Subject: Terrain evaluation, site selection, soil for engineering use.
Publications: Research papers.
Distribution: By request.

Massachusetts Institute of Technology
Research Laboratory of Electronics,
Room 26-341
Cambridge, Massachusetts 02139
Subject: Passive microwave techniques.
Publications: Research papers, research progress notes, MS and PhD theses.
Distribution: NTIS and by request for specific title.

University of Rhode Island
Electrical Engineering Department
Kingston, Rhode Island 02881
Subject: Development of photocathodes and arrays of photosensors, evaluation of image tubes and other pickup devices, reception and processing of extremely low frequency radio noise.
Publications: Research papers, MS and PhD theses, bibliography of published materials.
Distribution: Defense Documentation Center and specified distribution lists.

Forestry

Auburn University
Forestry Department
Auburn, Alabama 36830
Subject: Forestry.
Publications: Research papers, MS theses.
Distribution: Mailing list.

Clemson University
Department of Forestry
Clemson, South Carolina 29631
Subject: Forestry.
Publications: Research papers, MS theses.
Distribution: Mailing list of forestry schools, research stations and for university distribution.

Michigan State University
Forestry Department
East Lansing, Michigan 48823
Subject: Forestry.
Publications: Research papers, MS and PhD theses, bibliography.
Distribution: Mailing lists, by request for specific title. Bibliography available from the Michigan State University Agricultural Experiment Station.

Northern Arizona University
Forestry Department
Flagstaff, Arizona 86001
Subject: Forestry.
Publications: Research progress notes, MS theses.
Distribution: Mailing list for research progress notes.

Southern Illinois University
Forestry Department
Carbondale, Illinois 62901
Subject: Forestry.
Publications: MS theses.

Distribution: By request.

The University of Tennessee
Institute of Agriculture
Forestry Department, P.O. Box 1071
Knoxville, Tennessee 37901
Subject: Timber inventory.
Publications: Research papers, research progress notes, MS and PhD theses.
Distribution: On request from authors.

Geology

Colorado School of Mines
Geology Department
Golden, Colorado 80401
Subject: Geology.
Publications: Research papers, research progress notes, MS and PhD theses.
Distribution: Mailing lists, NTIS.

Cornell University
Geological Sciences Department
Ithaca, New York 14853
Subject: Earthquakes and faults.
Publications: Research papers, MS and PhD theses.
Distribution: Normal publication channels.

University of Missouri
Geology-Geophysics Department
Rolla, Missouri 65401
Subject: Geology.
Publications: Research papers, MS theses, and bibliography of publications.
Distribution: Request from Geology-Geophysics Department.

University of Nevada
Department of Geology
Reno, Nevada 89507
Subject: Geology.
Publications: Research papers, bibliography of publications.
Distribution: Exchange lists and sales.

The University of Tennessee
Geosciences Department
Knoxville, Tennessee 37916
Subject: Photogeology
Publications: MS and PhD theses, articles in journals.
Distribution: Mailing list for reprints.

University of Wyoming
Department of Geology
Laramie, Wyoming 82071
Subject: Geology.
Publications: Research papers, MS and PhD theses.
Distribution: Subscription to the semiannual publication "Contributions to Geology" available from the Department of Geology. Price varies.

Hydrology

University of Vermont
Geography Department
Burlington, Vermont 05401
Subject: Water resources.
Publications: Research progress notes, MS theses.
Distribution: By request.

Land Use

Dartmouth College
Geography Department
Hanover, New Hampshire 03755
Subject: Land use.
Publications: Research papers, contributions to books, informal bibliography of publications.
Distribution: Mailing list, government contract sponsors.

University of Georgia
Department of Geography
Athens, Georgia 30602
Subject: Land use.
Publications: Research papers, MS and PhD theses.
Distribution: On request from authors.

University of Kentucky
Department of Geography
Lexington, Kentucky 40506
Subject: Land use.
Publications: Research papgers, MS and PhD theses.
Distribution: Mailing list.

State University of New York
Department of Geography
Binghamton, New York 13901
Subject: Land use.
Publications: Research papers, MS theses.
Distribution: On request from authors.

Multidisciplinary

University of Alaska
Geophysical Institute
Fairbanks, Alaska 99701
Subject: No specific area designated.
Publications: Research papers, research progress reports, catalogs of remote-sensing data.
Distribution: Mailing list.

The American University
Biology Department
Washington, D.C. 20016
Subject: Wetlands, ocean dumping, African drought.
Publications: Research papers, MS theses.
Distribution: NTIS and by request for specific title.

University of Arizona
College of Agriculture
Watershed Management
Tucson, Arizona 85721
Subject: No specific area designated.
Publications: Research papers, MS theses.
Distribution: By request.

University of Arizona
Office of Arid Lands Studies
Tucson, Arizona 85719
Subject: Arid land applications.
Publications: Research papers, newsletter, and bibliography of publications.
Distribution: By request for specific title ($5 to $15 charge per publication).

University of California - Los Angeles
Geography Department
Los Angeles, California 90024
Subject: Environmental systems, especially coastal terrain, vegetation, and land use.
Publications: Research papers, research monographs, maps of land use, and MS and PhD theses.
Distribution: Office of Naval Research and DOD mailing lists, NTIS.

University of California - Riverside
Earth Sciences Department
Riverside, California 92502
Subject: Land use, computer techniques.
Publications: Research papers, MS and PhD theses.
Distribution: By request.

University of California - Santa Barbara
Department of Geography
Santa Barbara, California 93106
Subject: No specific area designated.
Publications: Research papers, research progress notes, books, contract reports, informal bibliography o publications.
Distribution: By request for specific title.

Colorado State University
College of Forestry and Natrual Resources
Department of Earth Sciences
Ft. Collins, Colorado 80521
Subject: Range and forest management, machine processing, geology.
Publications: Research papers, MS and PhD theses, bibliography of publication
Distribution: NTIS and by request for specific title (duplication cost where supply exhausted).

Cornell University
College of Agricultural and Life Sciences
Ithaca, New York 14893
Subject: Agriculture, land use.
Publications: Research reports, research progress notes, MS and PhD theses.
Distribution: On request from authors.

Cornell University
School of Civil and Environmental Engineering
Ithaca, New York 14853
Subject: No specific area designated.
Publications: Research papers, research progress notes, MS and PhD theses, newsletter.
Distribution: NTIS.

University of Delaware
College of Marine Studies
Newark, Delware 14711
Subject: Coastal vegetation, land use, water pollution, current circulation.
Publications: Research papers, research progress notes, contract reports, MS and PhD theses, bibliography of publications.
Distribution: Mailing lists.

Drexel University
Physics and Atmospheric Sciences
Philadelphia, Pennsylvania 19104
Subject: Lasar, radar studies.
Publications: Research papers, MS and PhD theses.
Distribution: By request for specific title.

Duke University
School of Forestry and Environmental Studies
Durham, North Carolina 27706
Subject: Environmental management, mapping.
Publications: Research reports.
Distribution: By request for reprints.

Eastern Michigan University
Geography-Geology
Ypsilanti, Michigan 48197
Subject: Coastal Processes - aquatic biology.
Publications: Research papers, bound volume of seminar reports, MS theses.
Distribution: By request to department head.

University of Illinois, Urbana - Champaign
Civil Engineering
Urbana, Illinois 61801
Subject: No specific area designated.
Publications: Research papers, research progress notes, books, MS and PhD theses.
Distribution: NTIS.

Iowa State University
Civil Engineering
Ames, Iowa 50010
Subject: No specific area designated.
Publications: Research papers, MS theses.
Distribution: On request from authors.

Long Island University
C. W. Post Center
Science Engineering Research Group
Greenvale, New York 11548
Subject: Multispectral photography applications.
Publications: Research papers, books, bibliography of publications.
Distribution: By request for specific title.

University of Maine
School of Forest Resources
Orono, Maine 04473
Subject: No specific area designated.
Publications: Research papers, research progress notes.
Distribution: By request.

Mississippi State University
Center for Environmental Studies
Mississippi State, Mississippi 39762
Subject: No specific area designated.

Publications: Research papers, research progress notes, MF and MS theses.
Distribution: On request from Forestry Department.

Ohio University
Geology Department
Porter Hall
Athens, Ohio 45701
Subject: Strip mining, water resources.
Publications: Research papers, MS theses.
Distribution: By request.

Oklahoma State University
School of Civil Engineering
Stillwater, Oklahoma 74074
Subject: No specific area designated.
Publications: Research reports, research project reports, MS theses.
Distribution: NTIS.

Old Dominion University
Physics and Geophysical Sciences
P.O. Box 6173
Norfolk, Virginia 23508
Subject: Land use, air pollution.
Publications: Research papers, research progress notes, MS theses.
Distribution: By request from department.

San Diego State University
School of Engineering
San Diego, California 92182
Subject: Land use, environmental pollution.
Publications: Research papers.
Distribution: Mailing list.

South Dakota School of Mines and Technology
Department of Geology and Geological Engineering
Rapid City, South Dakota 57701
Subject: Geology, water resources, soils.
Publications: Research papers.
Distribution: By request.

University of Southern Mississippi
Department of Geography
Hattiesburg, Mississippi 39401
Subject: Land use, forestry, water resources.
Publications: Research progress notes to NASA.
Distribution: By request.

Stephen F. Austin State University
School of Forestry
Nacogdoches, Texas 75961
Subject: Forestry, land use.
Publications: Research papers, MS theses.
Distribution: Mailing list.

University of Tennessee
Civil Engineering, Environmental/Water Resources
Knoxville, Tennessee 37916
Subject: No specific area designated.
Publications: Research papers, research progress notes, MS and PhD theses
Distribution: Depends on contractor/university agreement and individual faculty.

University of Tennessee
Plant and Soil Science
Knoxville, Tennessee 37901
Subject: Land use, soil surveys, drainage, forestry, and plant diseases.
Publications: Research papers, bulletins, MS and PhD theses.
Distribution: By request.

University of Texas - Austin
Geography Department
Austin, Texas 78712
Subject: No specific area designated.
Publications: Research papers, research progress notes, NASA special reports, books, MS and PhD theses
Distribution: NTIS.

University of Wisconsin - Madison
Environmental Monitoring and Data Group
Institute of Environmental Studies
Madison, Wisconsin 53706
Subject: Water quality, land use.
Publications: Research papers, research progress notes, books, bibliography of publications.
Distribution: By request for specific title.

University of Wisconsin - Milwaukee
College of Engineering and Applied Science

Milwaukee, Wisconsin 53201
Subject: Air pollution, computer techniques.
Publications: Research prpaers, MS and PhD theses.
Distribution: Mailing list.

Rangelands

Oregon State University
Rangeland Resources
Corvallis, Oregon 97331
Subject: Rangelands.
Publications: Research, research progress notes, MS and PhD theses.
Distribution: Mailing list.

Vegetation

University of Alaska
Institute of Arctic Biology
Fairbanks, Alaska 99701
Subject: Vegetation mapping
Publications: Research papers, research progress notes.
Distribution: NTIS and by request.

GEOGRAPHICAL INDEX

This index lists by state the universities and departments previously mentioned. Subject headings are given to assist the reader in locating a particular university or department in the previous sections.

Alabama

Auburn University. Forestry Department - Forestry.

Alaska

University of Alaska. Geophysical Institute-Multidisciplinary. Institute of Arctic Biology - Vegetation.

Arizona

University of Arizona. College of Agriculture - Multidisciplinary. Office of Arid Land Studies - Multidisciplinary. Northern Arizona University. Forestry Department - Forestry.

California

University of California - Berkeley. Remote Sensing Research Program - Remote Sensing institutions, laboratories, and programs.
University of California - Los Angeles. Geography Department-Multidisciplinary.
University of California - Riverside. Earth Sciences Department-Multidisciplinary.
University of California - Santa Barbara. Department of Geography-Multidisciplinary.
San Diego State University. School of Engineering-Multidisciplinary.
Stanford University. Remote Sensing Laboratory-Remote sensing institutes, laboratories, and programs.

Colorado

Colorado School of Mines. Geology Department-Geology.
Colorado State University. Department of Civil Engineering-Engineering. Department of Earth Sciences-Multidisciplinary.

Delaware

University of Delaware. College of Marine Studies-Multidisciplinary.

District of Columbia

The American University. Biology Department-Multidisciplinary.

Florida

University of Miami. Remote Sensing Laboratory-Remote Sensing institutes, laboratories, and programs.

Georgia

University of Georgia. Department of Geography-Land use.
Georgia Institute of Technology. Civil Engineering Department-Engineering.

Hawaii

University of Hawaii. Geography Department-Data Processing.

Idaho

University of Idaho. Geophotography and Remote Sensing Center-Remote sensing institutes, laboratories, and programs.

Illinois

University of Illinois. Civil Engineering-Multidisciplinary.
Southern Illinois University. Forestry Department-Forestry.

Indiana

Purdue University. Laboratory for Application of Remote Sensing (LARS)-Remote sensing institutes, laboratories, and programs.

Iowa

Iowa State University. Civil Engineering-Multidisciplinary.

Kansas

University of Kansas. Remote Sensing Laboratory-Remote sensing institutes, laboratories, and programs.
Kansas State University. Agronomy-Agriculture.

Kentucky

University of Kentucky. Department of Geography-Land use.

Maine

University of Maine. School of Forest Resources-Multidisciplinary.

Massachusetts

Boston University. Geography Department-Data processing.
Massachusetts Institute of Technology. Research Laboratory of Electronics-Engineering.

Michigan

Eastern Michigan University. Geography-Geology Department-Multidisciplinary.
University of Michigan. Remote Sensing Program-Remote sensing institutes, laboratories, and programs.
Michigan State University. Botany-Plant Pathology-Agriculture. Forestry Department-Forestry.

Minnesota

University of Minnesota. Remote Sensing Laboratory-Remote sensing institutes, laboratories, and programs.

Mississippi

University of Southern Mississippi. Department of Geography-Multidisciplinary.
Mississippi State University. Center for Environmental Studies-Multidisciplinary. Forestry Department-Multidisciplinary.

Missouri

University of Missouri. Geology-Geophysics Department-Geology.

Nevada

University of Nevada. Department of Geology-Geology.

New Hampshire

Dartmouth College. Geography Department-Land use.

New Mexico

National Park Service. Chaco Center-Archeology.
University of New Mexico. Technology Applications Center-Remote sensing institutes, laboratories, and programs.

New York

Cornell University. College of Agriculture and Life Science-Multidisciplinary.
Geological Sciences Department-Geology.
School of Civil and Environmental Engineering-Multidisciplinary.
State University of New York-Binghamton. Department of Geography-Land use.
Long Island University. Science Engineering Research Group-Multidisciplinary.

North Carolina

Duke University. School of Forestry and Environmental Studies-Multidisciplinary.

Ohio

Ohio University. Geology Department-Multidisciplinary.

Oklahoma

Oklahoma State University. School of Civil Engineering-Multidisciplinary.

Pennsylvania

Drexel University. Physics and Atomospheric Sciences-Multidisciplinary.

The Pennsylvania State University. Office of Remote Sensing of Earth Resources-Remote sensing institutes, laboratories and programs.

Rhode Island

University of Rhode Island. Electrical Engineering Department-Engineering.

South Carolina

Clemson University. Civil Engineering Department-Engineering. Department of Forestry-Forestry.

South Dakota

South Dakota School of Mines and Technology. Department of Geology and Geological Engineering-Multidisciplinary.

South Dakota State University. Remote Sensing Institute-Remote sensing institutes, laboratories, and programs.

Tennessee

The University of Tennessee. Civil Engineering-Multidisciplinary. Forestry Department-Forestry. Geosciences Department-Geology. Plant and Soil Science-Multidisciplinary. Space Institute-Remote sensing institutes, laboratories, and programs.

Texas

Stephen F. Austin State University. School of Forestry-Multidisciplinary.

University of Texas. Geography Department-Multidisciplinary.

Texas A & M University. Remote Sensing Center-Remote sensing institutes, laboratories, and programs.

Vermont

University of Vermont. Geography Department-Hydrology.

Virginia

Old Dominion University. Physics and Geophysical Sciences-Multidisciplinary.

Washington

University of Washington. Civil Engineering-Multidisciplinary. Remote Sensing Applications Laboratory-Remote sensing institutes, laboratories, and programs.

Wisconsin

University of Wisconsin-Madison. Institute of Environmental Monitoring-Multidisciplinary.

University of Wisconsin-Milwaukee. College of Engineering and Applied Science-Multidisciplinary.

Wyoming

University of Wyoming. Department of Geology-Geology.

Appendix H

OTHER SOURCES OF REMOTE SENSING INFORMATION

1. USER Services
EROS Data Center
Sioux Falls, South Dakota 57198

2. ASCS-USDA
Aerial Photography Field Services
2505 Parley's Way
Salt Lake City, Utah 84109

3. Soil Conservation Service - USDA
Photographic Division
Federal Building
Hyattsville, Maryland 20782

4. National Ocean Survey, NOAA
Coastal Mapping Division
C 3415
Rockville, Maryland 20852

5. Satellite Data Services Branch
World Weather Building
Room 606
Washington, D. C. 20233

6. Tennessee Valley Authority
Maps and Survey Branch
101 Haney Building
Chattanooga, Tennessee 37401

7. Environmental Protection Agency
Remote Sensing Division
P. O. Box 15027
Las Vegas, Nevada 89114

8. National Archives and Records
Cartographic Division
General Services Administration
Washington, D. C. 20408

9. American Society of Photogrammetry
University of New Mexico
Albuquerque, New Mexico 87131

10. American Society of Photogrammetry
105 N. Virginia Avenue
Falls Church, Virginia 22046

11. General Electric Photographic Laboratory
5030 Herzel Place
Beltsville, Maryland 20705

12. Pilot Rock, Inc.
Box 470
Arcata, California 95521

13. NASA-Ames Research Center
MS-204-7
Educational Programs Office
Moffett Field, California 94035
(Serving California, Alaska, Hawaii, Washington, Oregon, Idaho, Nevada, Arizona, Utah, Montana, and Wyoming)

14. NASA-Johnson Space Center
Public Information Office AP3
Houston, Texas 77058
(Serving North Dakota, South Dakota, Nebraska, New Mexico, Oklahoma, Texas, Kansas, and Colorado)

15. NASA-Lewis Research Center
Educational Services Office MSG-3
Cleveland, Ohio 44135
(Serving Minnesota, Wisconsin, Michigan, Indiana, Illinois, and Ohio)

16. NASA-Goddard Space Flight Center
Education Programs Office
Greenbelt, Maryland 20771
(Serving Maine, New Hampshire, Vermont, New York, Connecticut, Rhode Island, Delaware, Pennsylvania and Massachusetts)

17. NASA-George C. Marshall Space Flight Center
Public Services and Education
Marshall Space Flight Center, Alabama 35812
(Serving Iowa, Missouri, Arkansas, Louisiana, Mississippi, Tennessee, and Alabama)

18. NASA-Langley Research Center
Office of Public Affairs and Education
MS-15y
Hampton, Virginia
(Serving West Virginia, Virginia, Kentucky, North Carolina and South Carolina)

19. NASA-Kennedy Space Center
Office of Public Affairs and Education
PA-EPS
Kennedy Space Center, Florida 32899
(Serving Florida, Georgia, Puerto Rico, and the Virgin Islands)